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The MASTER-II Network of Robotic Optical Telescopes. First Results

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Abstract—The main stages in the creation of the Russian segment of the MASTER network of robotic telescopes is described. This network is designed for studies of the prompt optical emission of gamma-ray bursts (GRBs; optical emission synchronous with the gamma-ray radiation) and surveys of the sky aimed at discovering uncataloged objects and photometric studies for various programs. The first results obtained by the network, during its construction and immediately after its completion in December 2010, are presented. Eighty-nine alert pointings at GRBs (in most cases, being the first ground telescopes to point at the GRBs) were made from September 2006 through July 2011. The MASTER network holds first place in the world in terms of the total number of first pointings, and currently more than half of first pointings at GRBs by ground telescopes are made by the MASTER network. Photometric light curves of GRB 091020, GRB 091127, GRB 100901A, GRB 100906A, GRB 10925A, GRB 110106A, GRB 110422A, and GRB 110530A are presented. It is especially important that prompt emission was observed for GRB 100901A and GRB 100906A, and thar GRB 091127, GRB 110422A, and GRB 110106A were observed from the first seconds in two polarizations. Very-wide-field cameras carried out synchronous observations of the prompt emission of GRB 081102, GRB 081130B, GRB 090305B, GRB 090320B, GRB 090328, and GRB 090424. Discoveries of Type Ia supernovae are ongoing (among them the brightest supernova in 2009): 2008gy, 2009nr, 2010V, and others. In all, photometry of 387 supernovae has been carried out, 43 of which were either discovered or first observed with MASTER telescopes; more than half of these are Type Ia supernovae. Photometric studies of the open clusters NGC 7129 and NGC 7142 have been conducted, leading to the discovery of 38 variable stars. Sixty-nine optical transients have been discovered.

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1. INTRODUCTION

The first Russian robotic MASTER telescope, located near Moscow, was designed in 2002–2006 at the Sternberg Astronomical Institute of Lomonosov Moscow State University (SAI) [1, 2]. Over several years, the main principles for constructing an automated photometric system capable of addressing a wide range of tasks was developed on the basis of this instrument. First and foremost, unique software for the real-time reduction of large-format CCD images was developed.

The development of a network of robotic tele-

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scopes proceeded in 2008–2010 using the appreciably modernized MASTER-II systems installed near Blagoveshchensk, Irkutsk (Tunka village), Ekaterinburg, and Kislovodsk. The Russian segment of the network became fully operational in December 2010.

The MASTER-II robotic telescope design was developed at the SAI [2], and the Public Limited Company «Moskovskoe Obedinenie "Optika"» took over the production of these systems. Currently, there are no other systems similar to the network of optical, broadband MASTER telescopes in Russia, and the main characteristics of the MASTER network (field of view, limiting magnitude, bandwidth, synchronous photometry, polarization-sensitive photometry, pointing speed) exceed other such modern systems worldwide (ROTSE-III [3], TAROT [4], PROMPT [5], BOOTES [6]).

The MASTER-II broadband telescopes include a two-tube aperture system with a total field of view of eight square degrees, equipped with a 4000 pixel × 4000 pixel CCD camera with a scale of 1.85″/pixel, a universal photometer with B, V, R, and I filters realizing the Johnson–Cousins system, and polarizer filters.[1] Both of the optical tubes are installed on a high-speed mount with position feedback, which does not require additional guide instruments for exposures not exceeding three to ten minutes. The setup also has an additional degree of freedom—the variable angle between the optical axes of the two tubes. This makes it possible to double the field of view during survey observations simply by making separations in the tubes, or to conduct synchronous multi-color photometry with parallel-shifted tubes. The survey speed provided by a single MASTER-II system is 128 square degrees per hour with a limiting magnitude to 20^m on dark (moonless) nights.

The MASTER-II system is able to receive alerts sent through the GCN network, point at a set of coordinates provided by space gamma-ray observatories, and carry out synchronous multi-color and polarimetric observations of the prompt optical emission of GRBs.

Each system in the network is able to operate in autonomously, and also to interact with other systems in the network.

The structure of the network and the instruments and algorithms used in the network are described in detail in [2].

[1] Broadband polarizers manufactured using linear conducting nanostructure technology are used [2, 7].

2. DEVELOPMENT OF THE MASTER NETWORK IN 2008–2010

The MASTER-II systems were purchased by Moscow State University (the Caucasian Mountain Observatory of the SAI) and Ural Federal University (Kourov Observatory) in 2008. The reconstruction of the towers intended for the new telescopes was carried out by workman employed by the observatories. The first frames at the Caucasian Mountain Observatory were obtained at the beginning of 2009, and observations at the Kourov Observatory began four months later.

Construction of the MASTER observatories near Irkutsk (at the test site of the Institute of Applied Physics of Irkutsk State University in the Tunkin Valley) and Blagoveshchensk (on the territory of a former latitude station transformed into a botanical garden of the Far East Section of the Russian Academy of Sciences) began in July 2009. The establishment of network telescopes in these two far-eastern locations increases the interval of continuous sky monitoring coverage by five to six hours. Construction was complete by November 15, 2009, and test observations at the new locations were begun using test telescopes. All sites were equipped with 40-cm Hamilton-system telescopes starting in December 2010. Since that time, this first Russian robotic-telescope network has encompassed six time zones (Fig. 1 in the color insert).

The sets of equipment used at the different observatories in the network differ only slightly. The system installed at the observatory of the Ural Federal University does not include a very-wide-field (VWF) camera for synchronous observations of GRBs.

2.1. Checkout of the Systems

The first images obtained on these telescopes demonstrated the excellent quality of the optics used, however, they were not able to realize the full potential of the system due to factors that were not taken into account in their construction and software. Tests revealed the following main problems:

(1) appreciable non-parfocality of the filters, a temperature drift of the focus, and non-optimal adjustment of the optical system, leading to appreciable degradation of the image quality;

(2) an error in the design of the photometers, leading to the appearance of glare in the images and additional brightening of the field of view due to the sky background;

(3) insufficient rigidity of the units fixing the optical tubes, giving rise to shifts in the positions of stars in the focal plane during observations;

Fig. 1. The MASTER robotized optical network (January 2010). The broadband MASTER-II robotic telescopes and MASTER-VWF very-wide-field cameras are located at sites operated by Moscow State University (near Moscow and Kislovodsk), Ural Federal University (near Ekaterinburg), Irkutsk State University (in the Tunkin Valley), and Blagoveshchensk State Pedagogical University (Blagoveshchensk). The numbers show the mean number of clear nights in a year.

(4) a deficiency in the structure of the AstroHaven shelter, which required additional modification to adapt it to severe climatic conditions;

(5) a deficiency in the control interface of the telescopes, making it difficult to conduct observations according to arbitrary programs.

During the use of the telescopes, glare from bright stars located at the edge of the field of view was discovered in the images. This fault was corrected by installing light-shielding diaphragms in the telescope photometers. After additional adjustment of the optical system, it was possible to achieve a full-width at half-maximum (FWHM) of the stellar images of 1.8–2.4 pixels ($3''-5''$) over the entire field of view.

To eliminate dofocusing caused by the nonparfocality of the filters, changes were made to the control software of the system to provide automatic focus correction when the filters are turned on. The algorithm for the automatic focusing was also improved. Changes were made to the mechanical part of the focusing unit in order to eliminate backlash. All these measures made it possible to achieve an acceptable image quality for observations in the automated regime. The FWHM of stellar images for automated surveys rarely exceeds 2.5–3 pixels.

Changes were also made to the structure of the units fixing the telescope tubes to the mount, in order to enhance their rigidity. A new construction for the telescope dome was developed, based on experience with AstroHaven fiberglass shelters. The new shelters are used at the MASTER observatories near Blagoveshchensk and Irkutsk.

The first version of the telescope control software was tested. This software requires a fine and fairly long adjustment to adapt it to specific observing programs. Moreover, this adjustment depends on many parameters, such as the weather conditions, phase of the Moon (sky background), filter in which the observations are carried out, etc. Work on improving this software is ongoing. The main difficult is the requirement that the observatories be fully automated, which, in turn, requires descriptions of a large number of possible situations, which are usually processed by an observer. Many difficulties cannot be predicted beforehand, and long experience with use of the system is required to improve this situation.

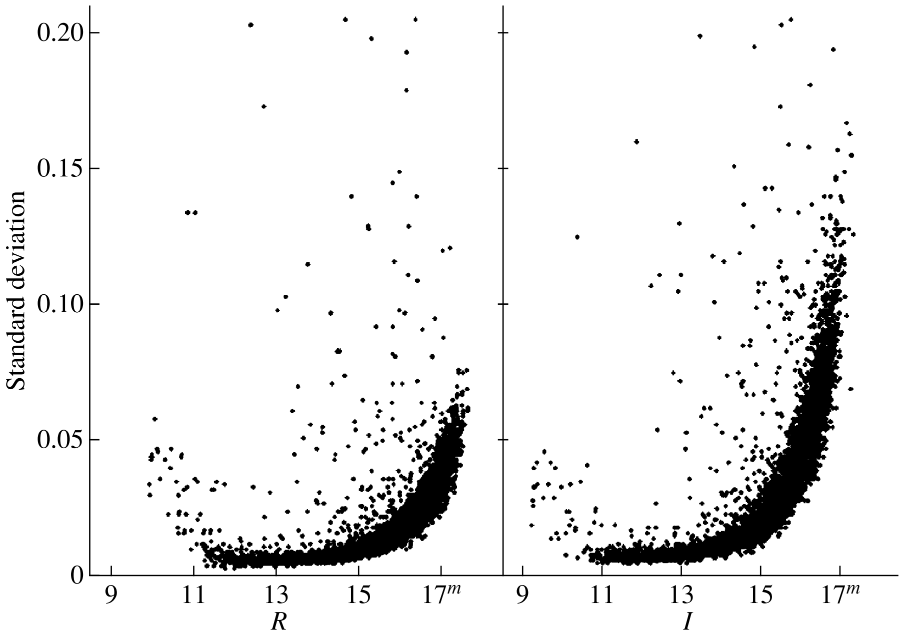


Fig. 2. Precision of the photometry.

Currently, the maximum period of fully automated operation of the system can reach three to four weeks.

2.2. Analysis of Photometric and Astrometric Properties of the MASTER-II System

Data on the precision of the phometry carried out with the MASTER telescopes were obtained using observations of the cluster NGC 188, which had been well studied earlier [8], with the Ural MASTER telescope. Frames with exposures of 120 s were obtained in the I, R, and B filters. Typical observing conditions for the Kourov Observatory correspond to a FWHM for stellar images of about three pixels, light haze, and weak light pollution. Photometry of stars in the cluster field was carried out using the IRAF/apphot package [9]. Figure 2 presents the distribution of the standard deviation and the brightness variations as a function of the magnitude for 30 frames in the R and I filters. The maximum photometric precision of 0.004^m has been achieved for observations of transiting exoplanets with the Ural and Tunka MASTER telescopes.

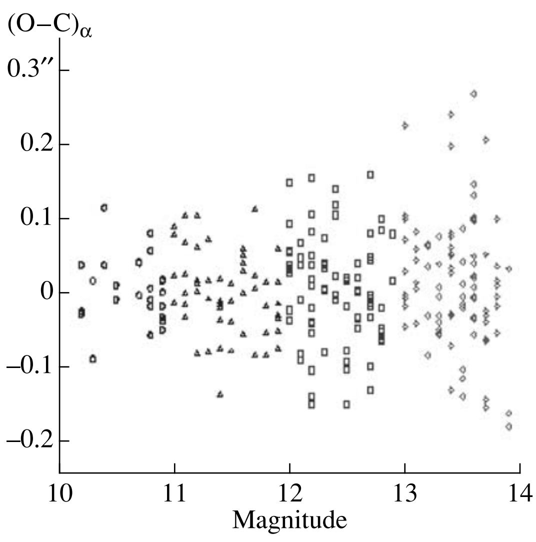


Fig. 3. Dependence of the O−C values for the right ascension of a star on the star's magnitude.

Appreciable non-linearity of the CCD detector at signal levels of more than 40 000 analog-to-digital units (ADUs) per pixel was discovered. For exposures of 180 s, typical for surveys, this corresponds to a 11.5^m star in the V filter.

The threshold for automatic detection of objects at the 3σ level during surveys was estimated from the best selected frames. This was 20^m for the B, V, and R filters and 19.2^m for the I filter at the Kislovodsk station. The threshold was 0.3^m better for the Tunka station, and 0.7^m–0.5^m worse for the Blagoveshchensk and Kourov stations, due to the appreciable sky background at these last two sites.

The precision of astrometric measurements was determined via an analysis of O−C diagrams constructed for the equatorial coordinates of stars as a function of their position in the frame, derived using the Eastern tube of the Ural MASTER-II telescope. The equatorial coordinates of the stars were calculated using the Izmccd package [10], taking into

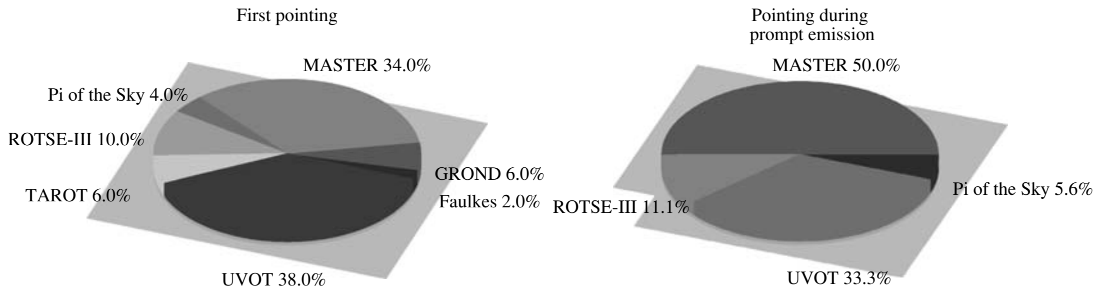


Fig. 4. Left: relative contributions of observatories to first pointings at GRBs. A time interval of a about year following the introduction of all telescopes in the MASTER network into operation, from September 2010 through June 2011, was analyzed using data from GCN circulars. Right: relative contributions of observatories to first pointings at GRBs at times of prompt emission. The data used to construct this diagram are presented in Tables 2 and 3.

account differential refraction and using a quadratic reduction model. The sample volume for this study was about 100 stars.

The maximum absolute O−C value was about 0.2″ at the edge of the frame, and the distribution of O−C values as a function of position in the frame corresponds to that expected for random errors.

Figure 3 presents the O−C dependence for the right ascension as a function of the stellar brightness. The UCAC-II [11] star catalog, which has coordinate errors less than 0.02″, was used for this purpose.

3. OBSERVATIONS

Observations on the MASTER telescopes are conducted in a completely automated regime. The required calibration exposures (flat fields, dark frames) are taken during morning and evening twilight, and the process of focusing and observing begins after sunset, when the sun is more than 9° below the horizon. The observations can be conducted in two modes: alert and survey. In the alert mode, an exposure is taken at a set of GRB coordinates received from the GCN center, in both tubes and mostly using polarizers. In the survey regime, the telescope takes separate exposures in the two tubes to provide maximum sky coverage, and the coordinates of a new area to be surveyed are chosen based on the criterion that there be a maximum number of galaxies in the field of view (for more detail, see [2]). The data are reduced in parallel with the observations in a real-time regime, with the aim of obtaining photometric and astrometric ties for all objects in a frame and carrying out searches for various types of optical transients. The principle characteristics of the data reduction are described in [2].

In this section, we present the results of observations of various types of transient phenomena with the MASTER telescopes.

3.1. Observations of GRBs

The main scientific task of the MASTER network of robotic telescopes was initially and remains observations of GRBs. In this section, we present a detailed history of GRB observations with our telescopes between September 2006 and February 2012. Earlier observational results have been published, for example, in [1, 12], and analyzed theoretically in [13–15]. Results obtained using the VWF cameras are described in [16]. In all, 89 observations of GRBs were carried out in this period. Optical emission was detected in eight cases, for GRB 091020, GRB 091127, GRB 100901A, GRB 100906A, GRB 100925A, GRB 110106A, GRB 110422A, GRB 110530A, and GRB 110801A. We will consider each of these GRBs in more detail. Table 1 presents the collected results for all the GRBs in chronological order, with important points in the development of the network indicated. This table clearly shows that significant results began to appear with the introduction of the Kislovodsk and Ural MASTER-II telescopes (two detections of optical emission and the first polarization observations). After the addition of the telescopes in Tunka and Blagoveshchensk, the network moved into first place in the world in terms of first pointings and first detections of prompt GRB emission; i.e., optical detections made before the GRB had ended (Tables 2 and 3, Fig. 4).

The most significant GRBs are considered in more detail below.

3.1.1. GRB 091020. Observations of GRB 091020 were carried out on the Kislovodsk MASTER-II telescope (SAI). Due to technical problems, the pointing was achieved only 3422 s after registration of the burst [135]. We detected a weak optical afterglow ($\sim17.5^m$). The first seven images were obtained in the R filter. Subsequently, an additional 130 frames were obtained with the polarizers, with exposures of 180 s [55]. The frames obtained with each of the polarizers were summed.

Table 1. Observations of GRBs with the MASTER network from September 2006–June 2011. The columns give (1) the name of the GRB; (2) the instrument on which the observations were carried out, I (VWF is the very-wide-field camera, VF is a MASTER-II telescope); (3), (4) the times from the GRB alert δT_a and from the trigger sent by a gamma-ray observatory δT_t (essentially the beginning of the GRB) to the beginning of the first MASTER optical observation, in seconds (sync denotes that the GRB was observed synchonously, i.e., continuously before, during, and after the GRB; prompt denotes that the optical emission was observed simultaneously with the gamma-ray emission); (5), (6) flags indicating the registration of optical emission O and the acquisition of polarization observations P of the GRB; (7) the GCN-circular number in which the results were published; (8) the site in the MASTER network where observations were carried out (K—Kislovodsk, M—Moscow, I—Irkutsk, U—Ural, B—Blagoveshchensk, T—Tunka); (9) the filter [C—white light (clear)], optical limit for the first frame, and exposure time in parantheses. An asterisk denotes GRBs registered by the FERMI/GBM with coordinate errors that are substantial and poorly known (for which the coordinate uncertainty can exceed the field of view of the VWF camera)

GRB	I	δT_a	δT_t	O	P	GCN	Site	Optical limiting magnitude
Only MASTER-I in Moscow and the VWF camera in Kislovodsk								
GRB 060929	VWF	39	42			5657 [17]	K	R 12.8 (100 s)
GRB 061002	VWF		97			5677 [18]	K	R 13.0 (100 s)
GRB 061213	VWF		303			5913 [19], 5914 [20], 5915 [21]	K	R 11.4 (50 s)
GRB 070219	VWF	15	76			6113 [22]	K	R 13.5 (420 s)
GRB 070223	VWF	1	496			6131 [23]	K	R 13.0 (180 s)
GRB 070224	VF	51	126			6138 [24], 6139 [25], 6140 [26]	M	C 16.2 (30 s)
GRB 070810	VF		125			6750 [27], 6752 [28]	M	C 14.8 (30 s)
GRB 071122	VF	69	151			7129 [29]	M	C 16.0 (30 s)
GRB 080205	VF		8 h			7261 [30]	M	C 20.0 (3000 s)
GRB 080319D	VWF	92	708			7454 [31], 7455 [32]	K	R 11.5 (5 s)
GRB 080605	VWF	12	46			7836 [33]	K	R 11.5 (100 s)
Start of the Irkutsk MASTER-VWF camera								
GRB 080822B	VF		1123			8123 [34]	M	C 18.8 (750 s)
GRB 081102	VWF	sync	sync			8464 [35], 8471 [36], 8516 [37]	K	R 11.1 (5 s)
GRB 081110	VF		7 h			8518 [38]	M	C 19.0 (2670 s)
GRB 081130*	VWF	sync	sync			8585 [39]	K	R 11.0 (5 s)
GRB 081130B*	VWF	sync	sync			8597 [40]	K	R 11.0 (5 s)
GRB 081215A*	VWF	sync	sync			8670 [41], 8671 [42], 8672 [43], 8673 [44], 8674 [45]	K	R 11.0 (5 s)
Start of the Kislovodsk MASTER-II in test mode*								
GRB 090305B*	VWF	sync	prompt			9004 [46]	K, I	R 9.5 (1 s)
GRB 090320B*	VWF	sync	prompt			9038 [47]	K, I	R 11.0 (60 s)
GRB 090328B*	VWF	sync	prompt			9065 [48]	K, I	R 9.1 (1 s)
Start of Ural MASTER-II								
GRB 090408B	WF		1.5 h			9111 [49]	U	R, V 17.0 (60 s)
GRB 090424	VWF	sync	prompt			9233 [50], 9252 [51]	K, I	R 9.0 (25 s)
GRB 090528B	WF		7 h			9468 [52]	U	R 19.0, V 18.1 (180 s)
Upgrade of Kislovodsk MASTER-II								
GRB 090715B	WF	19	484			9681 [53]	M	C 20.0 (3330 s)
GRB 090820*	VWF		9			9830 [54]	K	$R + P$ 11.0 (5 s)
GRB 091020	WF		3422	yes		10052 [55], 10231 [56]	K	
GRB 091127	WF	9	91	yes	yes	10203 [57]	K	

Table 1. (Contd.)

GRB	I	δT_a	δT_t	O	P	GCN	Site	Optical limiting magnitude
Start of Blagoveshchensk and Tunka MASTER-II in test mode; dismantling of Irkutsk MASTER-VWF								
GRB 091130A	WF	23	442			10213 [58]	B	C 16.0 (600 s)
GRB 091130B	WF	40	65			10216 [59]	B	C 15.0 (60 s)
GRB 100122A*	WF, VWF	30	59			10354 [60]	B	C 17.0 (60 s), VFW 11.5 (5 s)
GRB 100206A	WF	73	90			10391 [61]	B	VWF 11.5 (5 s)
GRB 100131A*	VWF	76	93			10393 [62]	B	VFW 10.0 (5 s)
GRB 100302A	WF	51	139			10463 [63]	B	C 17.0 (30 s)
GRB 100319A	WF	64	73			10527 [64]	B	C 16.0 (20 s)
GRB 100413A	WF	32	65			10582 [65]	T, B	C 17.0 (30 s)
GRB 100418A	WF	21	31			10633 [66]	T	C 14.5 (10 s)
GRB 100514A	WF	25	71			10763 [67]	U	C 17.0 (20 s)
GRB 100517A*	VWF		prompt			10769 [68]	B	C 8.0 (1 s)
GRB 100526A	WF	21 min	21 min			10798 [69]	B	U 18.2 (600 s)
GRB 100614A	WF	26	479			10853 [70]	K	P 20.9 (6120 s)
GRB 100718A*	VWF		prompt			10965 [71]	K, T	R 14.0 (25 s)
GRB 100816A	WF	21	1350			11105 [72]	K	C 17.2 (180 s)
Upgrade of Tunka MASTER-II								
GRB 100829A	WF	30	44			11157 [73]	K	P 15.7 (200 s)
GRB 100901A	WF	45	101	yes		11161 [74], 11163 [75], 11165 [76], 11178 [77]	T/B/U/K	
GRB 100902A	WF	27	104			11182 [78], 11185 [79]	U	P 17.0 (20 s)
GRB 100905A	WF	33	55			11216 [80]	T	P 16.5 (10 s)
GRB 100906A	WF	23	38	yes	yes	11228 [81], 11231 [82], 11235 [83]	T/B	
GRB 100925A	WF	2.5 h				11314 [84]	T, B	MAXI J1659-152
GRB 101008A	WF	23	53	yes		11328 [85]	U/T	
GRB 101020A	WF	22	106			11359 [86], 11361 [87]	U	$P+V$ 14.0 (20 s)
GRB 101112A	WF	21	36			11401 [88]	K	$P+V$ 15.7 (10 s)
GRB 101123A*	WF, VWF	23	111			11426 [89]	K	$P+V$ 15.0 (20 s)
GRB 110106A	WF	17	41			11523 [90], 11542 [91]	K	$P+V$ 16.0 (10 s)
Upgrade of Blagoveshchensk MASTER-II								
GRB 110106B	WF	23	44	yes		11548 [92], 11555 [93]	K	$P+V$ 16.0 (10 s)
GRB 110112A	WF	13 h	13 h			11558 [94]	K	R 19.0 (180 s)
GRB 110120A*	WF, VWF	24	63			11588 [95], 11598 [96]	K	$P+V$ 13.0 (10 s)
GRB 110201A	WF	21	46			11623 [97]	B	V 14.5 (10 s)
GRB 110207A	WF		30			11660 [98]	B/T	$P+V$ 14.1 (10 s)
GRB 110223A	VWF	7	147			11767 [99]	B	V 13.0 (5 s)

Table 1. (Contd.)

GRB	I	δT_a	δT_t	O	P	GCN	Site	Optical limiting magnitude
GRB 110315A	WF	44	89			11791 [100]	K	$P+V$ 17.3 (20 s)
GRB 110328A	WF	23	1257			11915 [101]	T	$P+R$ 19.1 (180 s)
GRB 110407A	WF	25	107			11897 [102], 11908 [103]	B	$P+V$ 17.8 (20 s)
GRB 110411A	WF	19	44			11919 [104], 11924 [105]	T	$P+R$ 17.5 (20 s)
GRB 110422A	WF	34	53	yes	yes	11960 [106], 12007 [107]	T	R 16.5 (10 s)
GRB 110426A*	VWF	sync	sync			11981 [108]	T	R 13.8 (20 s)
GRB 110520A	WF	23	53			12021 [109]	U, T	C 17.0 (10 s), $P+R$ 15.0 (10 s)
GRB 110521A	WF, VFW	32	92			12033 [110], 12040 [90]		$P+R$ 16.0 (20 s), C 12.0 (sync)
GRB 110530A	WF	12	73	yes		12050 [111]	T	$P+R$ 15.2 (10 s)
GRB 110610A	WF	30	55			12066 [112]	T	$P+R$ 15.0 (10 s)
GRB 110709A	WF	29	54			12120 [113]	T	$P+V$ 16.0 (10 s)
GRB 110801A	WF	–	101	yes		12138 [114]	T	$P+V$ 14.0 (10 s)
GRB 110820A	WF	45	133			12289 [115], 12300 [116]	T	$P+V$ 16.5 (30 s)
GRB 110915A	WF	15	31			12337 [117]	B	P 12.0 (10 s)
GRB 110921A	WF	7	53			12374 [118]	B, T	P 17.2/17.5 (10 s)
GRB 111022A	WF	29	47			12473 [119]	K	P 16.6 (10 s)
GRB 111022B	WF	22	583			12475 [120]	K	P 17.0 (10 s)
GRB 111103B	WF	19	42			12520 [121]	T	P 16.0 (10 s)
Swift J1922.7-1716	WF	28	98			12526 [121]	K	saturate
GRB 111204B	WF		115			12616 [122]	K	saturate
GRB 111215A	WF	26	381			12687 [123]	T, B, K	18.8
GRB 111215A	VWF	sync	sync			12687 [123]	T	12.0
GRB 120106A	WF	19	46			12811 [124], 12818 [125]	T	P 15.8 (10 s)
GRB 120116A	WF	10	31			12835 [126]	T	P 15.0 (10 s)
GRB 120118B	WF	1417	1437			12853 [127]	T	P 17.0 (120 s)
GRB 120227A	WF		9.5 h			12902 [128]	T	P 18.0 (180 s)
GRB 120229A	WF		1.3 d			12907 [129]	T	P 18.5 (180 s)
GRB 120202A	WF	73	81			12917 [130]	T	P 18.0 (20 s)
GRB 120211A	WF		77			12925 [131]	B	P 16.3 (20 s)
GRB 120213A	WF	26	49			12945 [132]	K	P 16.2 (10 s)
GRB 120219A	WF	22	105			12965 [133]	T, U	P 16.2 (10 s)
GRB 120219A	VWF	sync	sync			12977 [134]	T	C 11.5 (5 s)

* Here and below, the term test mode refers to observations carried out with a single telescope with half the diameter (∼20 cm) installed on the mount.

The 11 resulting summed frames for each of the polarizations and R images were reduced using the IRAF package. The resulting light curve (Fig. 5, Table 4) is described well by an exponential dependence $F \sim T^{-\alpha}$ with $\alpha = 1.2 \pm 0.1$, in agreement with subsequent observations [136]. The absolute magnitudes were calibrated using the 15 reference stars marked in Fig. 6.

3.1.2. GRB 091127. The Kislovodsk MASTER telescope pointed at GRB 091127 9 s after the alert (91 s after the burst) [137]. The supposed location of the GRB was 4° above the Western horizon. Nevertheless, we detected an optical transient. Just before sunset, 18 images with exposures from 20 to 130 s were obtained in the two orthogonal polarizations (Fig. 7). A rapidly decaying source is visible in these frames.

The extremely low elevation of the object hinders a precise analysis, especially of the polarization data. The optical depth grows dramatically with approach toward the horizon. Therefore, the four nearest stars to the object (closer than $1'$) were used as comparison stars. The remaining stars were sufficiently distant to hinder neglecting the variation of the background and absorption. Moreover, the analysis was complicated by the presence of the star GSC 0586202346 in the immediate vicinity of the GRB ($19'' = 5$ pixels).

Nevertheless, we constructed light curves in the two polarizations (Table 5, Fig. 8). The polarization curves disagree in the region of the fourth and fifth points, but this discrepancy can be explained by the extreme conditions under which these observations were taken (an elevation of $\sim$2.5°–3° at that time). In particular, due to differential refraction and atmospheric dispersion, the stars are elongated, and the characteristic shapes of the stars varies from frame to frame. Therefore, differences between the two polarizations can provide only tentative evidence for polarization.

The duration of the GRB was very short (about 10 s), and XRT X-ray observations began only an hour after the GRB (when MASTER was already no longer able to observe). Therefore, it is not possible to estimate the spectral slope between the optical and X-ray or gamma-ray for this GRB in the first few minutes.

3.1.3. GRB 100901A. Observations of GRB 100901A began nearly simultaneously on the Blagoveshchensk (45 s after the burst) and Tunka (47 s after the burst; Fig. 9) MASTER telescopes. Unfortunately, the weather at Blagoveshchensk hindered detection of the optical transient. The Tunka observations were carried out using only one of the two tubes. The object was low above the horizon, and the second tube was shielded by the cupola. The duration of the GRB in the gamma-ray was $T_{90} =$ 439 ± 33 s [138, 139]. Thus, the first five minutes of optical observations occurred simultaneous with the GRB. We detected a brightening of the object near 426 s (±40 s) [75], synchronous with a flare in the gamma-ray [139] and X-ray [140].

Table 2. Total number of pointings at GRBs since September 1, 2010

Project	Country	First pointing	GRBs recorded at time of prompt emission
Faulkes	England	1	0
GROND	Germany	3	0
MASTER	Russia	16	9
Pi of the Sky	Poland	2	1
ROTSE-III	USA	5	2
TAROT	France	3	0
UVOT*	–	19	6

* Space project.

Several hours after its detection, immediately after sunset, the Ural and Kislovodsk MASTER telescopes joined in the observations. Observations on all the MASTER observatories continued until sunrise at each of them, simultaneously in the various filters. This yielded about 14 h of continuous observations in the I, R, V, and white-light filters (Fig. 10).

In the first minutes, the GRB was observed synchronously in the optical (MASTER), X-ray (Swift-XRT), and gamma-ray (SWIFT/BAT). It is noteworthy that even the X-ray observations began after the MASTER optical observations. A clear correlation between the emission in all the ranges was observed. For example, a flare is clearly visible near 400 s in the optical, X-ray, and gamma-ray. Synchronous observations in the three ranges enable a good spectral analysis of the prompt emission, and the long series of observations revealed periodicity in the light curve. These results and the detailed photometry and spectral analysis of this GRB are published in [141].

3.1.4. GRB 100906A. The Tunka MASTER-II telescope pointed at the object 23 s after receiving the alert (38 s after the registration of the burst by the Swift space observatory [142]). A 13^m object was detected (Fig. 11). A series of frames using polarizers with exposures growing from 10 s to 180 s were obtained over the next four hours. The duration of the GRB in the gamma-ray was $T_{90} = 114 \pm 1.6$ s [143]. Thus, the first three frames of the series were obtained simultaneously with the GRB. Note that these are the

Table 3. First pointings at GRBs from September 2010 through June 2011. The columns give (1) the GRB name; (2) the observatory at which it was first observed; (3) the duration of the GRB in the gamma-ray according to Swift BAT data T_{90}; (4) the start time of the first optical observation T^{opt}_{start}; (5) a flag indicating whether the optical emission can be taken to be prompt; (6) the GCN-circular number in which information about the optical observations was published

GRB	Observatory	T_{90}, s	T^{opt}_{start}, s	GRB registered at time of prompt emission	GCN
110610A	MASTER	46.4	55	0	12066
110530A	MASTER	19.6	73	0	12050
110521A	MASTER	13.8	sync	1	12033
110520A	TAROT	15.7	45	0	12022
110519A		27.2		0	
110503A	UVOT	10	212	0	11991
110422A	MASTER	25.9	53	0	11960
110420B	GROND	0.084	(?)	0	11949
110420A	UVOT	11.8		0	
110414A	Faulkes	152	240	0	11932
110412A		23.4		0	
110411A	MASTER	80.3	44	1	11919
110407A	MASTER	145	107	1	11908
110402A	Pi of the Sky	60.9	sync	1	11864
110319B	GROND	14.5	12 h	0	11815
110319A	UVOT	19.3	65	0	11812
110318B	UVOT	4.8	77	0	11801
110318A		16		0	
110315A	MASTER	77	89	0	11791
110312A	GROND	28.7	147	0	11785
110305A	GROND	12	120	0	11774
110223B	UVOT	54	77	0	11754
110223A	Pi of the Sky	7	25	0	11763
110213B	P60	n/a	37.1 h	0	11732
110213A	ROTSE-III	48	27.1	1	11707
110212A	ROTSE-III	3.3	31	0	11700
110210A	UVOT	233	144	1	11687
110208A	UVOT	37.4	84	0	11674
110207A	MASTER	80.3	30	1	11660
110205A	ROTSE-III	257	82	1	11631
110201A	MASTER	13	46	0	11623
110128A	TAROT	30.7	73.7	0	11604
110119A	UVOT	208	67	1	11581

Table 3. (Contd.)

GRB	Observatory	T_{90}, s	T^{opt}_{start}, s	GRB registered at time of prompt emission	GCN
110112A	UVOT	0.5	80	0	11553
110106B	MASTER	24.8	44	0	11548
110106A	MASTER	4.3	41	0	11523
110102A	UVOT	264	149	1	11509
101225A	UVOT	1088	1387	0	11499
101224A	UVOT	0.2	83	0	11484
101219B	UVOT	34	156	0	11473
101219A	ROTSE-III	0.6	12	0	11462
101213A	UVOT	135	114	1	11448
101204A	UVOT	n/a	126199	0	11442
101201A	UVOT	n/a	14 h	0	11431
101129A		0.35		0	
101117B	UVOT	5.2	82	0	11411
101114A	GROND	>10	35 min	0	11409
101030A	UVOT	92	73	1	11389
101024A	UVOT	18.7	81	0	11370
101023A	UVOT	80.8	93	0	11371
101020A	MASTER	175	106	1	11359
101017A	ROTSE-III	70	(?)	0	11346
101011A	UVOT	71.5	1374	0	11338
101008A	MASTER	104	53	1	11328
100928A		3.3		0	
100924A	GROND	96	2052	0	11297
100917A	TAROT	66	261	0	11293
100915A	UVOT	200	140	1	11277
100906A	MASTER	114.4	38	1	11228
100905A	MASTER	3.4	55	0	11216
100904A	BOOTES-3	31.3	21528	0	11217
100902A	MASTER	428.8	104	1	11182
100901A	MASTER	439	101	1	11161

In columns (3) and (4), sync refers to a GRB observed synchronously, i.e., continuously before, during, and after the GRB; (?) means the exact time of the first observation is not known; n/a (not available) means that T_{90} is unknown.

first optical polarization observations of prompt GRB emission.

As in the case of GRB 100901A, the GRB was observed synchronously in the optical, X-ray, and gamma-ray during the first minutes, with the optical observations being polarization-sensitive. However, the behavior of GRB 100906A differs qualitatively from that of GRB 100901A. The optical light curve

Table 4. Observations of GRB 091020

$T - T_{\mathrm{GRB}}$, h	Filter*	Magnitude	Uncertainty	Filter	Magnitude	Uncertainty
1.0210	R	17.93	0.22			
1.0764	R	17.43	0.09			
1.1319	R	17.78	0.14			
1.1873	R	18.03	0.19			
1.2428	R	17.87	0.15			
1.2983	R	17.58	0.10			
1.3537	R	17.94	0.12			
1.6046	P\	18.65	0.11	P/	18.60	0.06
1.9830	P\	18.91	0.08	P/	18.46	0.06
2.2856	P\	19.04	0.08	P/	19.14	0.09
2.5629	P\	19.28	0.11	P/	19.11	0.09
2.8402	P\	19.36	0.09	P/	19.56	0.10
3.1174	P\	19.32	0.08	P/	19.38	0.09
3.3947	P\	19.35	0.06	P/	19.70	0.18
3.6720	P\	19.23	0.10	P/	19.53	0.11
3.9493	P\	20.07	0.17	P/	19.92	0.16
4.2266	P\	20.67	0.29	P/	20.03	0.19
4.5039	P\	20.07	0.22	P/	19.99	0.16

* P\ denotes the polarizer with the plane of polarization lying at 135° to the plane of the celestial equator, while P/ denotes the polarizer with the plane of polarization lying at 45° to the plane of the celestial equator.

Table 5. Observations of GRB 091127

$T - T_{\mathrm{GRB}}$, s	Filter*	Magnitude	Uncertainty	Filter*	Magnitude	Uncertainty
92.8	P\	14.68	0.25	P/	14.99	0.22
127.5	P\	15.00	0.25	P/	14.93	0.13
172.6	P\	15.15	0.25	P/	15.09	0.11
217.2	P\	14.95	0.20	P/	15.47	0.16
272.5	P\	15.01	0.16	P/	16.09	0.30
337.7	P\	15.59	0.38	P/	15.67	0.14
423.0	P\	15.67	0.29	P/	15.75	0.24
518.3	P\	15.67	0.26	P/	15.39	0.11
633.7	P\	15.66	0.55	P/	15.19	0.21

* P\ denotes the polarizer with the plane of polarization lying at 135° to the plane of the celestial equator, while P/ denotes the polarizer with the plane of polarization lying at 45° to the plane of the celestial equator.

of GRB 100906A does not display any peculiarities in the first hours, and essentially corresponds to the light curve of an ideal GRB (Fig. 12), in contrast to the data in the gamma-ray and X-ray, where flares are visible up to 200 s. The spectrum of this GRB also differs strongly from that for GRB 100901A. More de-

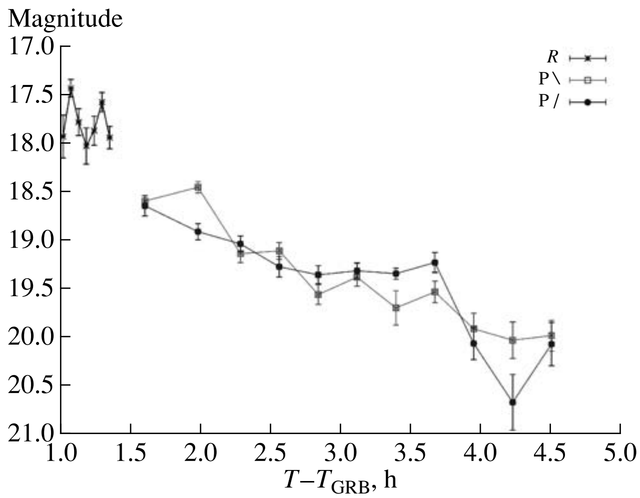


Fig. 5. Light curve for GRB 091020.

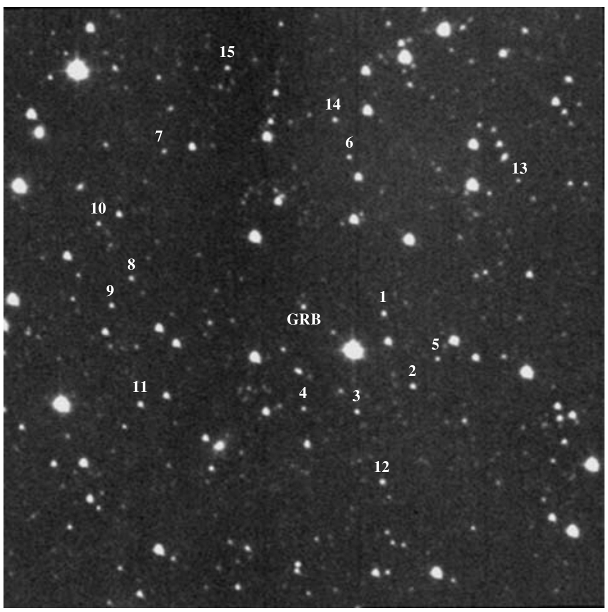


Fig. 6. Position of GRB 091020 and the comparison stars.

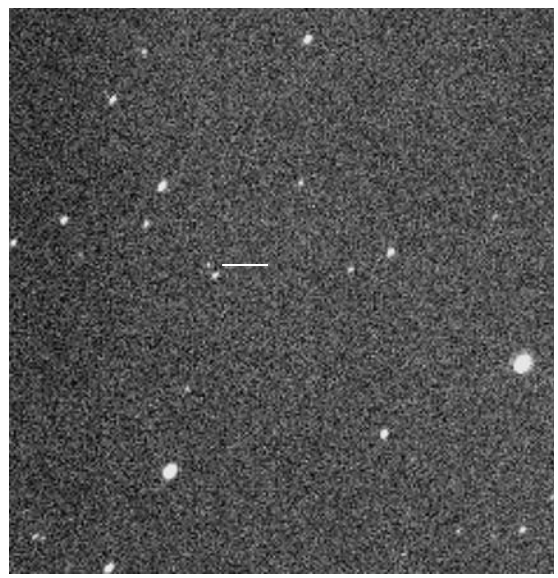


Fig. 7. First image of GRB 091127, obtained in one of the polarizations. The reference stars are the four nearest stars, apart from the star in the immediate vicinity of the GRB.

tailed information about the photometry and spectral information for GRB 100906A, and also a comparison with GRB 100901A, were published in [141].

A videorecording of this GRB is available at the site http://master.sai.msu.ru/static/GRB/grb100906.avi.

3.1.5. GRB 100925A/MAXI J1659-152. GRB 100925A was registered in an automated regime at the Tunka and Kislovodsk MASTER telescopes, just after sunset at each of them, simultaneously with Swift and MAXI [144–146]. This object has a Southern declination, and was not convenient for observation from Russia. Its elevation at Tunka was 15° above the horizon, and at Kislovodsk 22° above the horizon [84]. This explains why relatively few measurements are available, presented in Table 6.[2]

3.1.6. GRB 110106A. The Kislovodsk MASTER-II telescope was the first ground telescope to point at the short gamma-ray burst GRB 110106A [147], and began observations in both polarizations 41 s after the burst was registered (17 s after receiving the alert). A weak object was detected in one of the tubes in

[2] The time indicated in this and subsequent tables and figures, and also in the text, is UT.

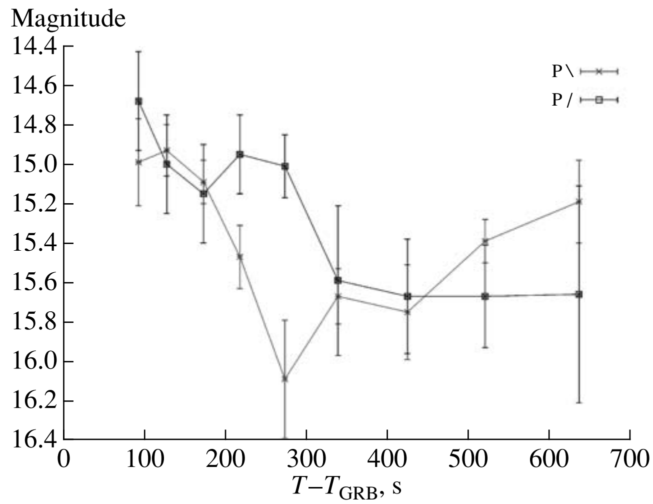


Fig. 8. Light curve of GRB 091127.

the second 10-s frame, which was rapidly reported in a GCN telegram [90]. It was later elucidated that the coordinates of the object determined from X-ray observations coincided with our coordinates. The Telescopio Nazionale Galileo on the Canary Islands reported the detection of a 24.5^m object at this same location 4.41 h later [148]. These observations are consistent with X-ray data indicating a maximum in Swift Burst Analyser data at $\sim$15 000 s [149].

3.1.7. GRB 110422A. The Tunka MASTER telescope was the first ground telescope to point at GRB 110422A [150], 53 s after the onset of the burst and 37 s after receiving the alert. The observations were carried out in both tubes and in both polarizations [106]. The exposures were successively increased from 10 to 180 s. An optical transient was detected in the very first 10-s frame. The observations were disrupted 35 min after they started due to poor weather conditions. It was possible to obtain 30 exposures, 15 in each polarization (Fig. 13, Table 7) [107].

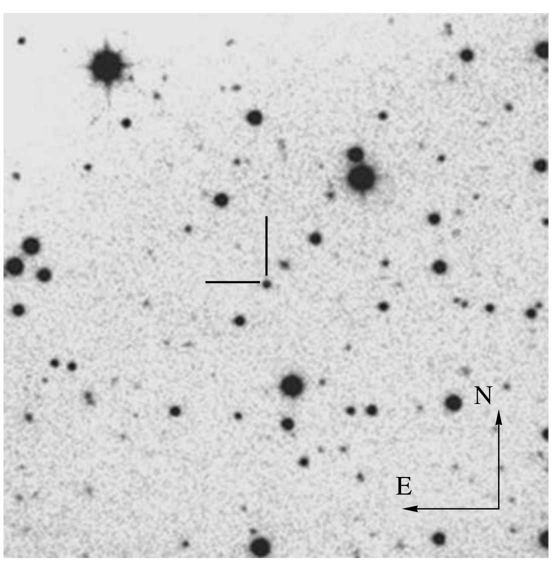


Fig. 9. Image of GRB 100901A.

In spite of the fact that the GRB formally ended before the first MASTER image (the GRB duration was $T_{90}^{\mathrm{BAT}} = 25.9 \pm 0.6$ s [151], $T_{90}^{\mathrm{KW}} \sim 40$ s [152]), the burst exceeded 3σ right to 115 s in the Swift Burst Analyser data [149]. At least two MASTER observations were made during this interval. Consequently, MASTER detected prompt emission at those times.

The light curve obtained for the first half-hour is very well described by a power-law brightness decrease, $F \sim T^{-\alpha}$, with $\alpha = 0.83 \pm 0.06$. Although some later observations, for example, $\sim$4–6 h later, indicate a slower decay corresponding to $\alpha = 0.55$ [153], analysis of our data jointly with data obtained at other observatories (Fig. 14) and the independent estimate $\alpha \sim 0.8$ of the NOT group [157] testify that the overall decay proceeded according to a single law without breaks, with $\alpha \sim 0.8$–0.9, from 100 s to a week after the burst. Note that the burst has a high redshift, $z = 1.77$, independently determined by different groups [162, 163].

To construct the spectrum, we translated our observed R magnitude into a flux using the Pogson formula

$$F_{\mathrm{GRB}}^R = F_0^R \times 10^{-0.4\,R}, \qquad (1)$$

where $F_0^R = 1.92 \times 10^{-9}$ erg s^{-1} cm^{-2} Å^{-1} = 3060 Jy [164] is the calculated flux of Vega in this filter.

In spite of the comparatively low Galactic latitude, $b \sim 10°$, the Galactic absorption is modest, $E(B -$

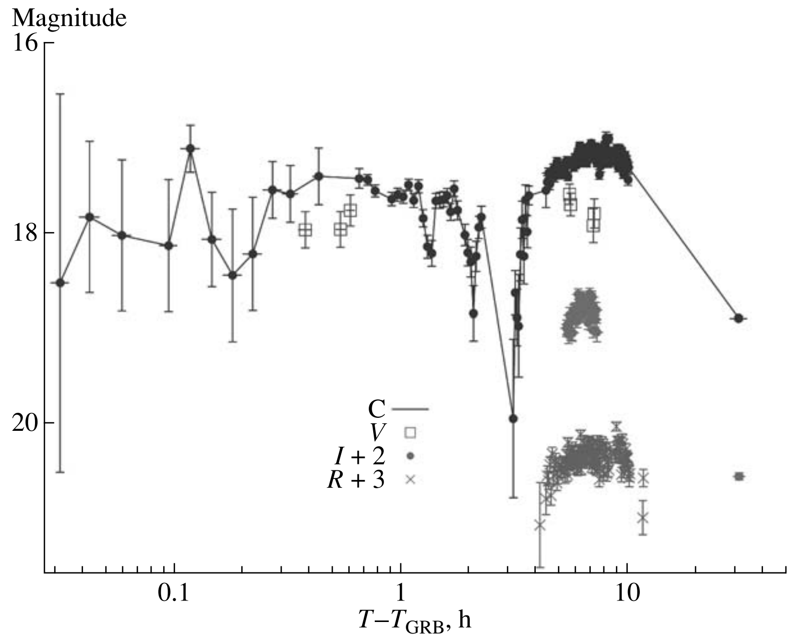


Fig. 10. Light curves of GRB 100901A in various filters.

$V) = 0.067$ [165], so that $A_R = 2.673E(B-V) = 0.18^m$. Taking into account absorption in the GRB host galaxy is much more complicated. This can be estimated from the surface density of hydrogen N_h, derived from soft X-ray observations. However, the disruption of dust in the vicinity of the GRB by its radiation and the possible low metallicity of GRB host galaxies [166] make such estimates uncertain, and they can differ by several factors of ten. Therefore, we will correct for only the Galactic absorption. Our data can be used to construct the spectrum from the gamma-ray to the optical using the first MASTER data point and the last significant BAT observation, and also using four points at the end of the MASTER observations that overlap with the first XRT observations.

All our calculations assume a single power-law spectrum $F_\nu \sim \nu^{-\beta}$ between neighboring ranges. Table 8 presents the photon indices $\Gamma = \beta + 1$ between the optical and gamma-ray ($\Gamma_{\gamma-\mathrm{opt}}$, first row) and between the optical and the X-ray ($\Gamma_{X-\mathrm{opt}}$) derived from a joint analysis of the MASTER, BAT, and XRT observations. These results show that the spectrum between the high-energy ranges and the

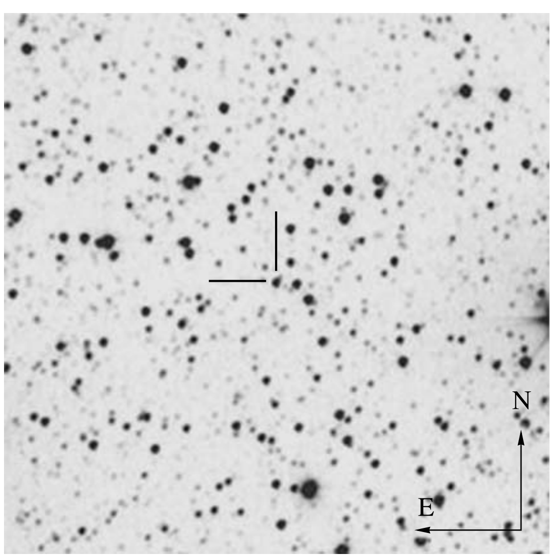


Fig. 11. Image of GRB 100906A.

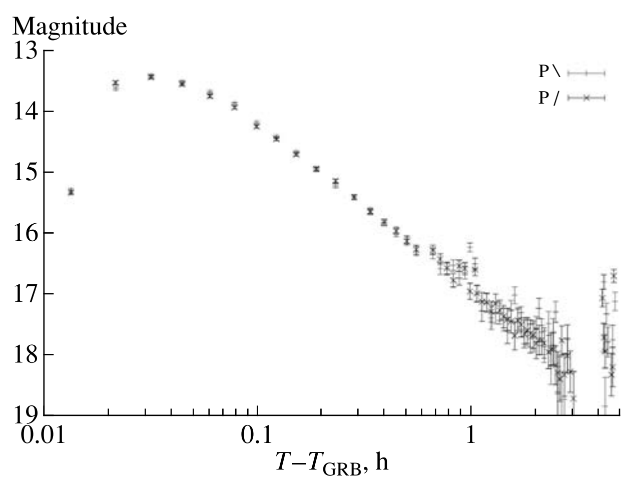


Fig. 12. Light curves of GRB 100901A in various filters.

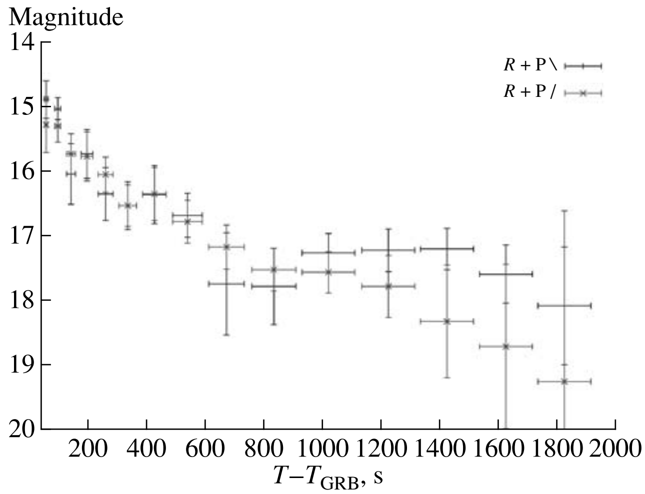


Fig. 13. Light curves of GRB 110422A in the R filter in both polarizations.

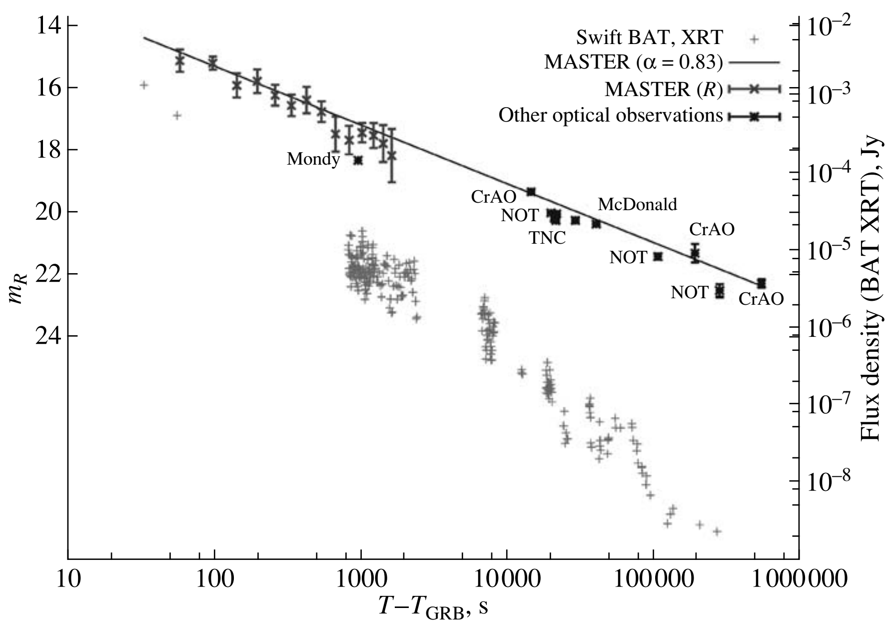


Fig. 14. Light curve of GRB 110422A obtained with the MASTER and other observatories compared with data published in GCN circulars [107, 153–161]. The line shows the mean slope of the curve $F \sim T^{-0.83\pm0.06}$ obtained from the MASTER data in the first half hour of observations. Although the rate of decrease slows at some specific times, overall, the initial rate of decrease is retained during the entire week of observations. The data used to construct this plot can be found at the site http://master.sai.msu.ru/static/GRB/110422a.txt.

optical is not unique; i.e., the X-ray, and even moreso the gamma-ray, spectrum cannot be continued to the optical. All the BAT and XRT data were obtained using the Swift Burst Analyser [149].

3.1.8. GRB 110530A. The Tunka MASTER telescope was the first ground telescope to point at GRB 110530A [167], 12 s after receiving the alert (73 s after the burst) [111]. The burst itself was fairly short ($T_{90} = 19.6$ s), and the optical observations were only able to measure the afterglow. MASTER observed with successively increasing exposure times from 10 to 180 s in both polarizations. No optical transient was detected in the first few frames, and it was possible only to derive upper limits, from 15.2^m (for the first 10-s exposure) to 18.0^m. A weak object with $R = 18.3$ was detected in the 10th frame with an exposure of 130 s at a time of 673 s (Fig. 15, Table 9).

The object was visible at the detection limit, giving rise to large uncertainties. The light curve shows that it was strongly variable, appearing and disappearing

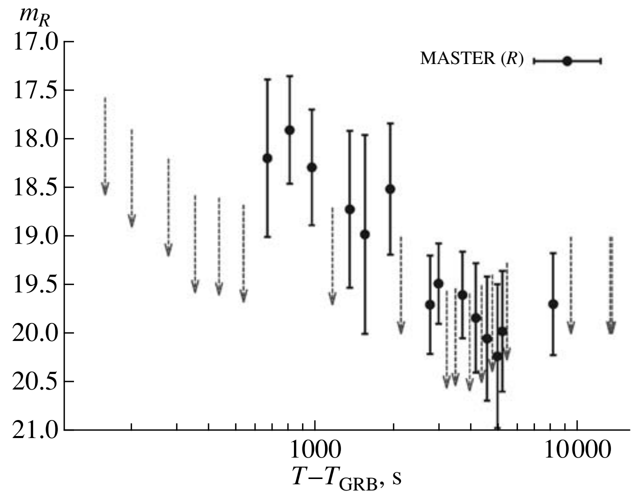


Fig. 15. Light curve of GRB 110530A obtained at the Tunka MASTER telescope in the R filter (the dashed vertical lines with arrows indicate upper limits). The results of observations of the visible optical transient are presented in Table 9, and the full light curve with the optical magnitudes reached can be found at http://master.sai.msu.ru/static/GRB/110530a.txt.

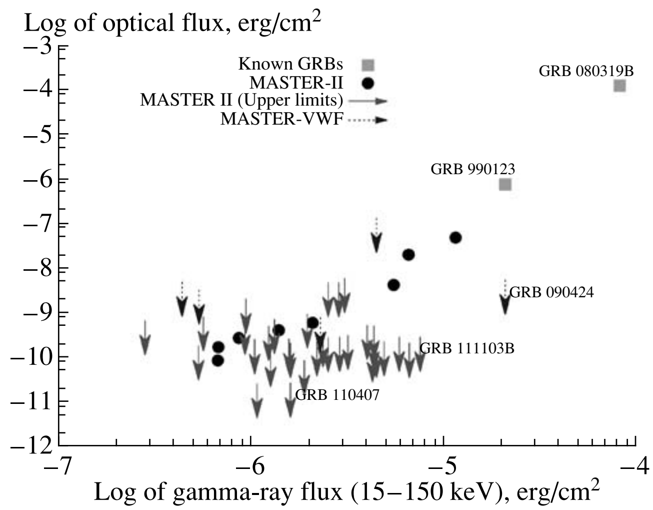


Fig. 16. Dependence of the optical flux on the gamma-ray flux. Upper limits obtained by the MASTER-II telescopes are shown by solid vertical arrows, and synchronous limits with the MASTER-VWF camera by dashed vertical arrows. The filled circles show MASTER-II observations of GRB 100901A and GRB 100906A, and the hollow squares observations of GRB 080319B and GRB 990123.

in the frames. Formally, we can derive the decay law $F \sim T^{-0.83\pm0.2}$. In spite of the weakness of the object from the start of the X-ray observations (~ 500 s), it is possible to derive good estimates of the spectral slope at some times (corresponding to frames in which the object is clearly visible). The resulting measurements of the photon index are presented in Table 10.

As for the previous burst, the X-ray–optical spectrum does not agree with the gamma-ray–optical spectrum. When constructing the spectra, we corrected for optical absorption in our Galaxy corresponding to $A_R = 0.14^m$.

3.1.9. Two types of GRBs. The fundamental difference in the observed light curves and spectra for GRB 100901A and GRB 100906A [141] suggests that these two objects have a different physical nature. In the case of GRB 100901A, synchronous variations in all three bands (optical, X-ray, and gamma-ray) were observed (i.e., during the prompt emission); one example is the synchronous flare observed near 400 s. In contrast, the optical emission of GRB 100906A does not show any correlation with its harder emission. This difference is supported by the spectral data. Allowing for the uncertainty in the optical absorption in the host galaxy, the spectrum of

GRB 100901A can be described using a single power law from the optical to the gamma-ray, while, in the case of GRB 100906A, only the soft X-ray component may tentatively be correlated with the optical emission during the interval of prompt emission [141].

To test this idea, we search through more than 9000 GCN telegrams, finding 25 cases of synchronous optical and gamma-ray observations of GRBs, listed in Table 11. These GRBs exhibit two different types of behavior. For some objects, we see a clear correlation between the optical and gamma-ray or X-ray emission, while for other objects there is no such correlation. The appearance of two classes of GRBs may be natural in a model in which there is a system of two shocked regions in a relativistic jet. The inner shock arises because the explosion is not instantaneous—the relativistic particles continue to enter the channel and push up against the medium heated by the outer shock. If the optical emission arises as a result of synchrotron cooling of electrons in the inner shock, this emission will be correlated with the gamma-ray and X-ray emission, and the three bands will display a common spectrum. The spectra of the bursts listed in Table 11 indicate that, in the cases of GRB 100901A, GRB 060607, and GRB 090709, the entire spectrum from optical to gamma-ray can be described by a single power law $F_\nu \sim \nu^{-0.5\pm0.2}$, as is characteristic of synchrotron emission, when the electrons very rapidly lose energy. On the contrary, in GRB 100906A and the remaining GRBs in Table 11, there is no correlation between the optical emission and the gamma-ray/X-ray emission. It may be that, here, the optical emission arises in the leading shock front, and the light curve shows the smooth emergence of the leading shock into the self-similar afterglow regime with a power-law index $\alpha = 1.07 \pm 0.03$.

A critical test for this paradigm is provided by polarization observations. If emission arises in the inner shocked region in an ordered magnetic field, it should be linearly polarized.

3.1.10. "Dark" observations of the prompt emission of GRBs. The MASTER system is able to establish only upper limits to the optical emission of most GRBs. However, due to the very rapid pointing, the first frames are sometimes obtained before the GRB prompt emission has ended; i.e., the derived optical limits are limits on the prompt optical emission of the GRB. Moreover, more than ten VWF cameras operate in the MASTER network, which can be used to obtain images of the error squares of the GRBs synchronously with the gamma-ray observations. Synchronous observations have a great advantage over alert-triggered observations for two reasons. First, strong observational selection effects can be present in alert-triggered observations: it is possible to observe prompt emission only from fairly long bursts (no shorter than 30–40 s), since the delays between the gamma-ray and optical observations (due to processing at the gamma-ray telescope, transmission of the sigal to the Earth, resending the information to the ground observatory, pointing of the telescope) can be large, comprising of the order of 10 s for each step. Second, alert-triggered observations will never be able to detect the prompt optical emission from short, hard GRBs whose durations (to 2 s) are shorter than the signal-processing time on all existing or planned gamma-ray observatories, not to mention the additional delays associated with sending the alert telegram and pointing the optical instruments. No researchers have yet been able to detect prompt optical emission from short GRBs, or even to place upper limits on such emission.

Currently, 12 VWF cameras are operating in the MASTER network (six in Kislovodsk and two in each of Blagoveshchensk, Tunka, and Argentina). The cameras in Blagoveshchensk and Tunka and two of the cameras in Kislovodsk are installed in a single structure with the MASTER-II telescopes, and operate in accordance with the MASTER-II program; the remaining cameras are installed on individual mounts and can operate in accordance with their own program, maximally covering the field of view of the Swift BAT gamma-ray detector. Information about the current BAT field of view and GRB alerts are both transmitted through the GCN network. More detailed information about each GRB observed synchronously and films of synchronous observations within the error box can be found at the site http://master.sai.msu.ru/static/syncronous.html.

Apart from the successful observations described above, the MASTER-II telescopes have currently carried out more than 35 "dark" observations of the prompt emission in 15 different GRBs, as well as five GRBs observed synchronously using the MASTER-VWF camera.

Figure 16 depicts the corresponding optical limits as a function of the GRB flux (15–150 keV) for all "dark" bursts observed by the MASTER network. The same figure presents the MASTER observations of GRB 100901A and GRB 100906A for comparison, together with observations of the well known bursts GRB 080319B [168] and GRB 990123 [169]. Most of the upper limits lie below the level of the successful observations, indicating a clear lack of detectable optical emission compared to the gamma-ray emission (Fig. 16). For example, the optical brightness limit for GRB 090424, which was observed synchronously with wide-field cameras, is two orders of magnitude lower than the brightness of GRB 990123 in the region of high gamma-ray fluxes. The optical limits for GRB 111103B and GRB 110413A are one and

Table 6. Optical data for GRB 100925A/MAXI J1659-152

Date and time	$T-T_{\rm GRB}$, days	Magnitude	Uncertainty	Observatory
2010-09-25 12:09:27	0.098	16.08	0.25	Tunka
2010-09-26 02:54:12	0.274	16.14	0.2	Tunka
2010-09-26 16:25:36	1.276	16.2	0.1	Kislovodsk

a half orders of magnitude lower than the observed values for GRB 100906A in the region of medium gamma-ray fluxes. Moreover, the optical limits for comparatively weak GRBs (GRB 110407, for example), are at least an order of magnitude lower than the observed values for GRB 100901A. Thus, it is clear that the spectra of GRBs cannot be universal from the optical to the gamma-ray range, and there must exist so-called "dark bursts" with very weak or absent optical emission.

Note that, in addition to GRBs detected by the Swift and Integral observatories, all the MASTER telescopes and cameras react to GRB data arriving from the FERMI telescope. In contrast to Swift, the FERMI observatory is not specialized for GRB observations, so that the onboard instruments yield GRB coordinates with accuracies no better than $\sim$10 deg^2. We have numerous alerts and synchronous observations of GRBs with the FERMI observatory. Unfortunately, the poor coordinate information hinders searches for possible optical emission, making it difficult to assert with 100% probability that the entire error box has been covered by the cameras. Currently, no optical sources associated with GRBs registered by FERMI have been detected.

3.2. Observations of Supernovae

The search for supernovae with the MASTER network which was begun in Vostryakovo [1] was continued in November 2009. At that time, the network included the Kislovodsk and Ural telescopes [small test antennas capable of detecting only the brightest supernovae (13^m–14^m) were installed at Blagoveshchensk and Tunka until August and December 2010, respectively].

We adopted the following method for searching for supernovae. One of the robotic telescopes acquires a frame, reduces this frame, and generates a list of unidentified objects, which can be inspected over the internet using a specially designed, interactive web interface. Unidentified objects near a galaxy are considered to be supernova candidates. We considered a galaxy to be near an object if the distance from the object to the center of the galaxy was less than twice the maximum radius of the 25^m isophote obtained from the HyperLeda database [170]. In addition to cataloged stars and normal galaxies, the objects found in a frame can include "noise," stars that are not included in stellar catalogs (we use the USNO B1 [171]), weak galaxies, and galactic nuclei. Noise and moving objects (asteroids) can be efficiently rejected by taking a repeat frame of the area 40–60 min later. The situation with regard to "blank spots" in catalogs is worse, especially because it is precisely near average and bright galaxies that one finds many uncataloged stars in the USNO B1 list. As a result, this approach overestimates the number of supernova candidates. Since the final verdict is made by an observer, this appreciably slows the search process. It takes human observers too long to examine the candidates proposed by the robotic sys-

Table 7. Optical observations of GRB 110422A

$T-T_{\rm GRB}$, s	$R+$P\	Uncertainty	$R+$P/	Uncertainty
58.5	15.28	0.43	14.89	0.29
98.1	15.3	0.25	15.03	0.17
143.0	15.73	0.31	16.04	0.47
197.3	15.77	0.38	15.73	0.38
261.0	16.05	0.27	16.35	0.41
336.4	16.53	0.32	16.53	0.37
427.1	16.35	0.41	16.36	0.45
539.4	16.78	0.33	16.68	0.34
672.5	17.17	0.34	17.74	0.79
833.7	17.52	0.33	17.78	0.59
1019.3	17.56	0.32	17.26	0.3
1223.8	17.78	0.48	17.22	0.33
1423.0	18.32	0.87	17.2	0.32
1623.7	18.71	1.27	17.59	0.45
1822.8	19.25	2.64	18.08	0.91

* P\ denotes the polarizer with the plane of polarization lying at 135° to the plane of the celestial equator, while P/ denotes the polarizer with the plane of polarization lying at 45° to the plane of the celestial equator.

Table 8. Photon indices Γ in various ranges for GRB 110422A. The next-to-last column gives Γ in the optical to gamma-ray and X-ray, and the last column in the X-ray

Time, s	Range for comparison	$\Gamma_{\gamma-\mathrm{opt}}$, $\Gamma_{X-\mathrm{opt}}$	Γ_X
59 ± 5	γ	1.18	2.70
834 ± 75	X-ray	1.46	2.06
1019 ± 90	X-ray	1.47	2.07
1223 ± 90	X-ray	1.45	2.01
1423 ± 90	X-ray	1.41	1.86

Table 9. Results of optical observations of GRB 110530A

$T - T_{\mathrm{GRB}}$, s	Exposure, s	R magnitude	δm
660	110	18.2	0.8
803	130	17.9	0.6
975	160	18.3	0.6
1361	180	18.7	0.8
1554	180	19.0	1.0
1940	180	18.5	0.7
2751	180	19.7	0.5
2965	180	19.5	0.4
3660	180	19.6	0.4
4111	180	19.8	0.6
4540	180	20.0	0.6
4968	180	20.2	0.7
5189	180	20.0	0.6
8111	180	19.7	0.5

Table 10. Spectral observations of GRB 110530A

Time, s	Range for comparison	$\Gamma_{X-\mathrm{opt}}$	Γ_X
660 ± 55	X-ray	1.86	2.28
803 ± 65	X-ray	1.97	2.69
975 ± 80	X-ray	1.91	2.65

tem to keep up with the incoming list of candidates. However, this problem has gradually been reduced over one-to-two years, since the robotic telescopes have "learned" during the course of the search, as the computer catalog has been supplemented by the results obtained by the observers. Moreover, after the first year of operation on a given telescope, a database of frames of the entire accessible sky is made, which can be used to visually and automatically (see below) verify supernova candidates. This is especially important, since the IAU Central Bureau for Astronomical Telegrams list of recent supernovae (http://www.cbat.eps.harvard.edu/cbat.html) does not consider candidates without reference frames with the same telescope, in which the candidate is absent.

Sixteen candidate supernovae had been discovered by the end of May 2011. In addition, frames of 36 supernovae were taken during the survey before their initial discovery by other authors (see Table 12[3]). Thus, the efficiency of the search was less than 30%. Analysis showed that a large fraction of the supernovae that were observed but not found by the robotic approach were not discovered due to the absence of a "second pass," due to instability of the sky opacity during the night. Recall that the Blagoveshchensk and Tunka sites, which are the richest in clear nights, only began to operate in the network from the end of 2010. Further, due to the slow internet connection in Tunka, examination of the supernova candidates began only in the Spring; i.e., the period of the first year with the longest nights was lost. The statistics of "bad" nights over 2.5 years included mainly the Ural and Moscow-region sites, which have the poorest weather conditions.

The supernovae 2008gy [172] and 2009nr [184] discovered in the robotic MASTER survey are among the best-studied, nearby Type Ia supernovae, and are practically located in intergalactic space. Supernovae similar to 2008gy and 2009nr can be distinguished as a special class of Type Ia supernovae that are not subject to the effects of ordinary and additional extragalactic gray absorption and chemical evolution. Analysis of a Hubble diagram for this class of supernovae confirms the acceleration of the expansion of the Universe [225].

The number of discovered supernovae appreciably grew toward the end of 2011, due to the introduction of supernova searches using the transient method. In contrast to the standard method, the transient method verifies the absence of an object on archive frames of the observatory, making it possible to substantially reduce the number of spurious candidates and enhance the efficiency of supernova searches. The nine supernovae 2011ha, 2011gg, 2011hh, 2011iq, 2011ib, 2011il, 2011io, 2011jy, and 2012K were discovered from October 2011 through January 2012, as well as several supernovae that had

[3] A fuller version of this table is available at the site http://master.sai.msu.ru/static/SN/first_observations.html.

Table 11. Successful observations of optical emission synchronous with the gamma-ray emission

GRB	Filter	Magnitude	$T - T_{\rm GRB}$, s	T_{90}, s	Observatory
100906A	P	15.1	40	114.4	MASTER
100901A	P	16.1	111	439	MASTER
090812	W	16.0	26.5	66.7	RAPTOR
090709A	W	17.1	31.3	89	RAPTOR
090618	W	14.1	23.9	113.2	ROTSE-IIIb
081203A	W	14.5	167.5	249	UVOT
081109A	R	17.8	110	180	TAROT
081029	W	16.5	86	270	ROTSE-IIIC
081008	W	14.5	41.9	185.5	ROTSE-IIIc
080810	W	13.7	38	106	ROTSE
080607	W	14.8	26	79	ROTSE-IIIb
080603B	W	14.1	24	60	ROTSE-IIIb
080413	W	12.8	21	46	ROTSE-IIIc
080319B	W	10.9	0	>50	TORTORA + Pi of the sky
080310	W	18.8	99	365	UVOT
080205	W	18.1	65	106.5	KAIT
071031	r	15.0	60	180	GROND
061126	W	12.3	23	70.8	RAPTOR
061121	W	14.9	77	81.3	ROTSE-IIIa
061007	W	13.6	27	75.3	ROTSE-IIIa
060927	W	16.5	16	22.5	ROTSE-IIIa
060904B	W	17.3	19	171.5	ROTSE-IIIc
060607	H	13.3	–	102.2	REM
060418	z	15.3	40	103.1	PROMPT
041219A	R_c	19.2	240	520	RAPTOR
990123	W	11.8	22	63	ROTSE-I

been verified spectrally and had received an official name (Table 12).

Simultaneous with the search for supernova candidates, multi-color photometric observations of Type Ia supernovae were carried out, and were used to determine the contribution of the cosmic vacuum energy (dark energy). During the survey, 387 supernovae were observed with various degrees of coverage. Detailed photometry of these supernovae is now being carried out. The Appendix presents a table of supernovae present in frames obtained by the MASTER robotic network.

3.3. Observations of Transients

There does not exist a strict definition of an optical transient. This is due to the enormouse variety of "temporal" phenomena arising in the sky, with a variety of completely unrelated physical origins (see, for example, the classification of transients presented in the context of the GAIA project [226, 227]).[4]

If we define a transient as a new (unidentified) astrophysical object in a frame, such an object could be

[4] http://www.ast.cam.ac.uk/ioa/wikis/gsawgwiki/index.php/Triggers.

Table 12. Supernovae discovered or observed first by the MASTER network (2008–June 2011)

No.	Date*	Nearby galaxy	m^{**}	Discovered by	Name of supernova	Type of supernova	Comments
1	30.10.2008	PGC 1584648	17.7	P. V. Balanutsa	2008gy	Ia	Special article [172], CBET [173]
2	13.04.2009	Anon.	17.7	CRTS	2009eb	–	CBET [174], Atel [175]
3	13.04.2009	Anon.	18.3	CRTS	2009ec	–	CBET [174], Atel [175]
4	17.09.2009	UGC 2175	18.2	LOSS	2009iz	Ib/c	CBET [176]
5	08.10.2009	IC 1320	16	R. Arbour	2009jr	Ia	CBET [177]
6	14.10.2009	Anon.	15.5	CRTS	2009kk	Ia	CBET [178]
7	08.11.2009	IC 1549	18	LOSS	2009li	Ia	CBET [179]
8	17.11.2009	Anon.	17.4	CRTS	2009lv	Ia	CBET [180]
9	25.11.2009	Anon.	19.3	CRTS	2009nh	Ic	CBET [181]
10	27.11.2009	J022619-1857	14.8	SWIFT BAT	2009nz	Ic	Alert observation GRB 091127 [57]
11	02.12.2009	NGC 3839	16.6	Itagaki	2009mh	Ia	CBET [182]
12	15.12.2009	Anon.	17.4	CRTS	2009mv	Ia	CBET [183]
13	22.12.2009	UGC 8255	13.6	P. V. Balanutsa	2009nr	Ia	Discovered independently [184], CBET [185]
14	23.12.2009	NGC 2839	18.3	LOSS	2009mx	Ia-p	CBET [186]
15	27.01.2010	PGC 51710	R15.3	P. V. Balanutsa	2010V	Ia	CBET [187]
16	28.02.2010	UGC 10679	16.5	L. Cox, T. Puckett	2010ag	Ia	CBET [188]
17	06.03.2010	Anon.	16.9	ROTSE	2010ai	Ia	CBET [189]
18	28.02.2010	MCG 0341142	18.2	LOSS	2010ak	Ic	CBET [190]
19	08.03.2010	MCG 130910	17.2	J. Newton, T. Puckett	2010at	Ia-p	CBET [191]
20	09.03.2010	Anon.	17.5	CRTS	2010ay	Ic	CBET [192]
21	12.03.2010	Anon.	15.2	CRTS	2010ba	Ia	CBET [193]
22	02.05.2010	NGC 5177	17	R. Itagaki; PTF	2010cr	–	CBET [194]
23	15.05.2010	PGC 1895764	15.2	P. V. Balanutsa	2010db	–	Star with high proper motion, CBET [195]
24	29.05.2010	PGC 43005	17.6	V. P. Shumkov	2010ea	–	CBET [196]
25	01.06.2010	NGC 3184	17.2	Itagaki	2010dn	–	CBET [197, 198], Atel [199, 2000], bright blue variable star
26	31.08.2010	Anon.	16.6	Leonini, G. Guerrini	2010ho	Ia	CBET [201]
27	29.08.2010	Anon.	18.7	CRTS	2010hu	Ia	CBET [202]
28	20.09.2010	NGC 2333	17.6	LOSS	2010ie	IIp	CBET [203]
29	19.10.2010	UGC 03552	16.7	P. V. Balanutsa	2010iz	IIP	Discovered independently, Atel [204]
30	26.10.2010	PGC 066672	17.2	P. V .Balanutsa	–	Ia	Atel [205]
31	27.10.2010	UGC 04543	16.3	P. V. Balanutsa	2010io	Ic	Discovered independently, Atel [206, 207]
32	04.11.2010	UGC 0595	19	P. V. Balanutsa	2010jo	Ia	Discovered independently, Atel [207, 208]

Table 12. (Contd.)

No.	Date*	Nearby galaxy	m^{**}	Discovered by	Name of supernova	Type of supernova	Comments
33	08.11.2010	Anon.	18.1	ROTSE	2010ke	Ia	CBET [209]
34	31.10.2010	Anon.	18.5	T. A. Fatkhullin et al.	2010kj	Ia	CBET [210]
35	03.11.2010	Anon.	18.2	CRTS	2010le	Ia	CBET [211]
36	29.11.2010	SDSS J120939	15.5	P. V. Balanutsa	–	–	Not confirmed, ultra-bright SNIIn(?), Atel [212]
37	19.12.2010	SDSS J124138	17.9	P. V. Balanutsa	–	–	Not confirmed, Atel [213]
38	01.01.2011	Anon.	18.6	CRTS	2011P	IIn	CBET [214]
39	29.01.2011	Anon.	19	ROTSE	2011ad	Ia	CBET [215]
40	13.02.2011	PGC 021381	13.9(V)	I. V. Kudelina	2011aa	Ia	Discovered independently, Atel [216]
41	27.02.2011	PGC 2440228	19.0	V. P. Shumkov	–	–	Not confirmed, Atel [217]
42	14.03.2011	IC 3862	16.2	Gavin	2011az	IIP	CBET [218]
43	01.03.2011	Anon.	15.8	La Sagra Survey	2011bk	Ia	CBET [219]
44	09.03.2011	PGC 2128586	19.7	V. P. Shumkov	–	–	Not confirmed, Atel [220]
45	23.03.2011	Anon.	19.2	CRTS	2011bt	Ia	CBET [221]
46	26.03.2011	082752.77+704606.0	19.1	V. M. Lipunov	–	SNIIn(?)	Spectrum on SAO 6-m, Atel [222]
47	26.04.2011	PGC 045903	16.2	V.PП. Shumkov	–	Ia	Atel [223]
48	05.05.2011	NGC 5425	15.9	J. Newton, T. Puckett	2011ck	IIP	CBET [224]

* Date of discovery or first observation by MASTER for supernovae discovered by other observatories.
* The magnitude at the time of discovery is in white light if not noted otherwise.

(1) a dwarf nova,

(2) a classical nova,

(3) a luminous red nova,

(4) a Type Ia supernova,

(5) a flare on a red dwarf whose brightness goes below the limit of the survey and working catalog ($\sim 20^m - 21^m$),

(6) a Type Ib/c supernova or Type II supernova,

(7) a super-bright supernova,

(8) an orphan afterglow, as a rule, associated with a GRB whose hard-energy beam does not coincide with the direction toward the Earth,

(9) an afterglow from an ordinary short or long GRB,

(10) a flare in the nucleus of a distant active galaxy or quasar,

(11) an asteroid or comet.

However, from the point of view of formal searches for transients in the framework of our project, we can distinguish two groups of transient objects:

(1) slow transients—uncataloged objects that are absent from earlier frames and prevent on two survey frames for a given night (e.g. supernovae, cataclysmic variables, dwarf and classical novae, and many others),

(2) fast transients—uncataloged objects with characteristic flare times of the order of a minute, which are visible in both tubes in one of two passages during a given night [short transients can also be detected with VWF cameras (e.g. optical afterglows of GRBs, orphan afterglows)].

Table 13. Transients discovered by the MASTER network

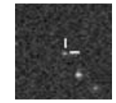
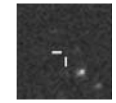
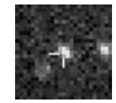
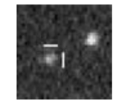
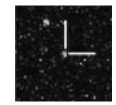
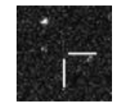
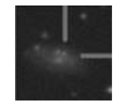
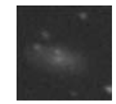
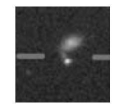
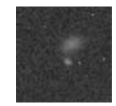
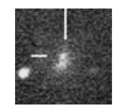
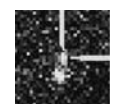
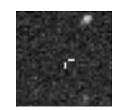
No.	Site*	Date	α	δ	Filter**	m***	Ref****	Interpretation	Discovery frame	Reference frame*****
1	K	2010-06-14.86	$15^h50^m11.27^s$	$12°16'42.2''$	R, V	18.0	[228]	Rediscovery of SN 2010er [229]		
2	K	2010-09-27.99	07 19 48.91	40 53 32.3	C	16.7	[230]	Flare on dwarf nova [231], discovery of AAVSO 249637		
3	K	2010-10-01.98	01 53 47.24	30 38 44.0	V	17.9	[232]	CV(?) [233] or discovery of dwarf nova AAVSO 249699		
4	K	2010-10-19.06	06 49 52.83	28 22 27.6	C	16.7	[204]	SN inUGC 03552		
5	K	2010-10-26.72	21 23 21.37	17 15 18.9	C	17.2	[205]	SNIa three weeks after maximum [234]		
6	K	2010-10-27.01	08 43 21.46	45 44 16.5	C	16.3	[206]	SN 2010io, independent discovery		
7	K	2010-11-04.75	00 57 35.54	−01 23 31.2	C	17.0	[208]	SN 2010jo, independent discovery		
8	K	2010-12-19.01	12 41 38.10	47 47 51.4	C	17.9	[213]	SN in SDSS J124138.20+474742.9		
9	K	2010-12-09.72	01 32 41.20	34 38 09.1	C	17.7	[235]	Rediscovery of dwarf nova AAVSO 251445		
10	T	2011-01-24.64	12 09 39.35	56 09 17.3	C	15.5	[212]	SNIIn(?)		

Table 13. (Contd.)

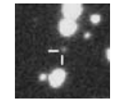
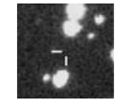
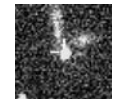
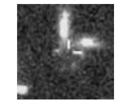
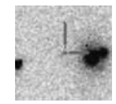
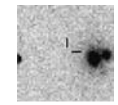
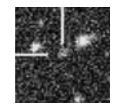
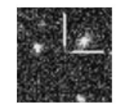
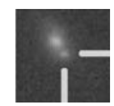
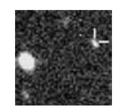
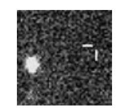
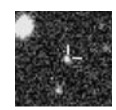
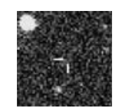
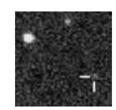
No.	Site*	Date	α	δ	Filter**	m***	Ref****	Interpretation	Discovery frame	Reference frame*****
11	K	2011-01-26.83	05 45 47.15	09 12 00.3	C	18.4	[236]	Optical flare of X-ray source 2XMM J054547.2+091159		
12	B	2011-02-13.54	07 36 42.49	74 26 35.1	C	13.9	[216]	Rediscovery of SN 2011aa [237]		
13	T	2011-02-27.27	16 18 30.77	53 24 31.7	C	19.0 ± 0.4	[217]	SN candidate в PGC 2440228		
14	K	2011-03-09.59	12 50 29.47	38 29 45.8	C	19.7 ± 0.4	[220]	SN candidate in PGC 2128586		
15	K	2011-03-26.76	08 39 18.37	17 43 15.9	C	18.9 ± 0.4	[238]	Asteroid		
16	T	2011-03-26.59	08 27 52.77	70 46 06.0	C	19.1	[222]	Object with one spectral line [239, 240]		
17	K	2011-04-26.77	13 12 56.30	47 27 15.0	C	16.2	[223]	SNIa, independently discovered and confirmed PTF [241]		
18	T	2011-05-08.78	15 22 06.02	30 20 42.7	C	18.3	[242]	(?)		
19	T	2011-05-12.77	17 29 00.0	75 18 42.5	C	17.7	[243]	"M8 star high Galactic Latitude Flare," flare on brown dwarf		
20	U	2011-05-14.86	07 37 21.02	85 43 23.7	C	19.5	[243]	(?)		

Table 13. (Contd.)

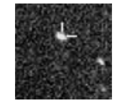
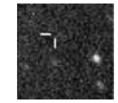
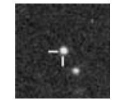
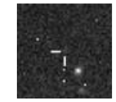
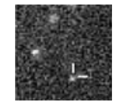
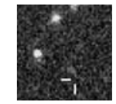
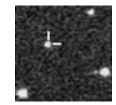
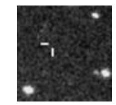
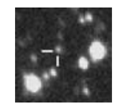
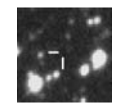
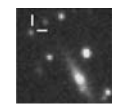
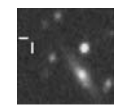
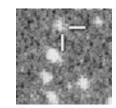
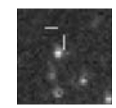
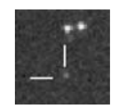
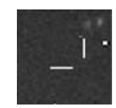
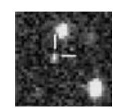
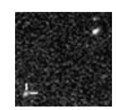
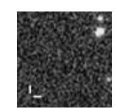
No.	Site*	Date	α	δ	Filter**	m***	Ref****	Interpretation	Discovery frame	Reference frame*****
21	T	2011-05-14.69	13 13 20.36	69 26 48.3	C	16.1	[243]	SNIIn(?)		
22	T	2011-06-04.77	16 39 42.75	12 24 14.4	C	16.4	[244]	Rediscovery CV Discovery CSS		
23	T	2011-08-09.68	16 05 58.15	+27 59 21.6	C	17.2	[245]	SN candidate in galaxy group SDSS J160557.60+275921.1, SDSS J160558.47+275931.0, SDSS J160558.95+275921.8		
24	K	2011-08-17.97	23 20 22.36	44 43 30.8	C	15.9	[246]	Flare on UGSU variable VSX J232022.3+444330		
25	T	2011-08-19.70	19 58 28.24	12 12 52.3	C	16.4	[247]	Proposed dwarf nova MASTER-OT195828.24+121252		
26	T	2011-08-25.61	17 52 42.98	29 04 10.6	C	17.1	[248]	SN 2011ft (Type Ib), rich in calcium, 2–3 weeks after maximum [249]		
27	B	2011-09-01.60	20 06 28.62	56 29 12.9	C	17.7	[250]	Dwarf nova, weak ($B \sim 22^m$) blue object on Palomar plates.		
28	T	2011-09-03.66	00 22 47.85	32 43 24.7	C	18.1	[251]	Flare of 2MASS 00224790+3243256		
29	T	2011-09-30.90	03 57 40.87	10 09 55.2	C	18.5	[252]	SN 2011ha Type Ia, $z = 0.094$, 10 days after maximum [253]		
30	K	2011-10-07.86	00 46 21.04	−09 09 29.2	C	17.9	[254]	Independent discovery of SN 2011gg (Type Ia), $z = 0.055$ [255]		

Table 13. (Contd.)

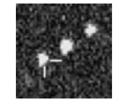
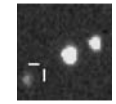
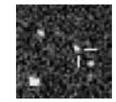
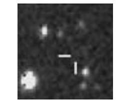
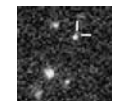
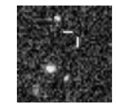
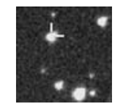
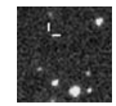
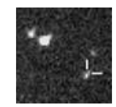
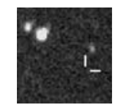
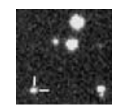
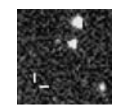
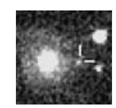
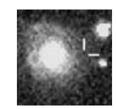
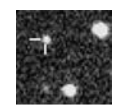
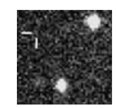
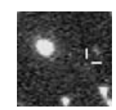
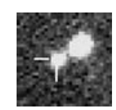
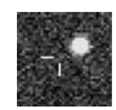
No.	Site*	Date	α	δ	Filter**	m***	Ref****	Interpretation	Discovery frame	Reference frame*****
31	B	2011-10-24.79	08 14 43.89	12 54 59.7	C	14.8	[256]	Dwarf nova MASTER-OT081443.89+125459		
32	B	2011-10-26.65	02 57 04.61	+49 47 43.3	C	16.9	[257]	SN2 011hh Type Ia, $z = 0.015$ [258]		
33	B	2011-10-29.36	02 48 49.60	−08 04 30.0	C	18.3	[259]	SN 2011iq Type Ia, $z = 0.015$ [260]		
34	K	2011-11-04.97	06 47 38.82	45 57 42.5	C	15.2	[261]	(?)		
35	K	2011-11-07.75	03 11 16.23	37 05 02.7	C	17.5	[261]	V0965 Per		
36	K	2011-11-04.69	22 56 14.61	38 08 15.3	C	17.2	[261]	Dwarf nova		
37	K	2011-11-15.08	11 44 39.27	+35 58 03.9	C	16.8	[262]	SN 2011ib Type IIn,pec, 2 months after maximum [263]		
38	K	2011-11-20.00	05 21 41.66	−04 11 09.9	C	16.9	[262]	Dwarf nova		
39	K	2011-11-20.03	07 35 08.62	19 11 26.1	C	17.0	[264]	SN 2011il Type Ia, 1 month after maximum [265]		
40	T	2011-11-27.48	23 02 47.60	08 48 09.8	C	16.2	[266]	SN 2011io Type Ia, at maximum $z = 0.04$ [267]		

Table 13. (Contd.)

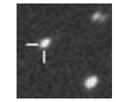
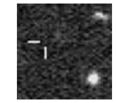
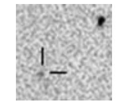
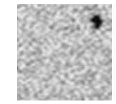
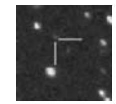
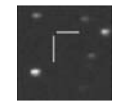
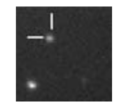
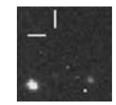
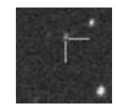
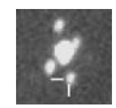
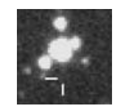
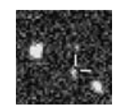
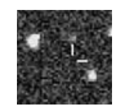
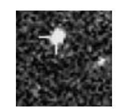
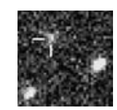
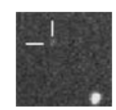
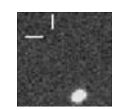
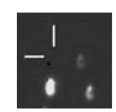
No.	Site*	Date	α	δ	Filter**	m***	Ref****	Interpretation	Discovery frame	Reference frame*****
41	T	2011-12-01.63	03 48 50.94	+71 42 02.0	C	16.0	[268]	Dwarf nova		
42	B	2011-12-11.88	11 44 44.53	+32 30 11.3	C	16.5	[269]	Rapid transient(!)		
43	B	2011-12-15.49	21 43 51.21	+31 53 24.6	C	17.2	[270]	PSN		
44	T	2011-12-21.60	01 51 47.45	+09 49 46.3	C	14.2	[270]	Very bright flare		
45	T	2011-12-22.75	08 41 27.37	+21 00 54.4	C	16.9	[270]	3^m flare of cataclysmic variable		
46	B	2011-12-28.57	06 17 30.02	+35 40 36.6	C	14.5	[271]	CV [272]		
47	K	2011-12-30.02	10 36 30.69	−00 35 23.8	C	18.4	[273]	M dwarf [274]		
48	K	2012-01-01.70	10 51 23.02	67 25 28.3	C	14.6	[275]	Flare of X-ray and radio source [276]		
49	B	2011-12-30.79	10 53 57.03	+23 22 34.5	C	16.5	[277]	SN 2011jy Type II, 1.5 months after maximum $z = 0.04$ [278]		
50	B	2012-01-04.56	00 48 22.33	+74 17 57.5	C	14.1	[277]	Mirida		

Table 13. (Contd.)

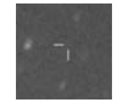
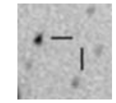
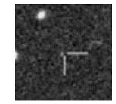
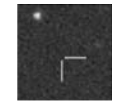
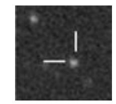
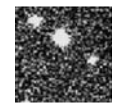
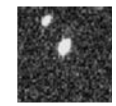
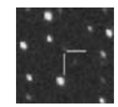
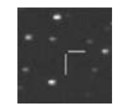
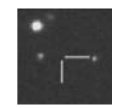
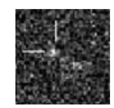
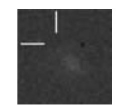
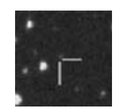
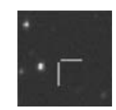
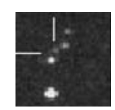
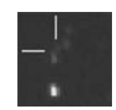
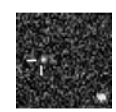
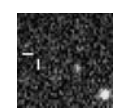
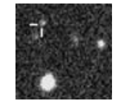
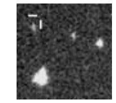
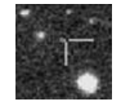
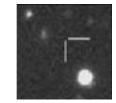
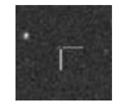
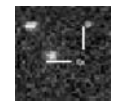
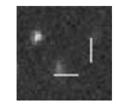
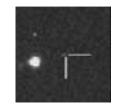
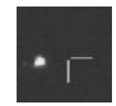
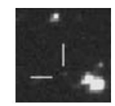
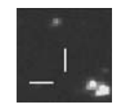
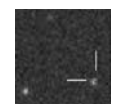
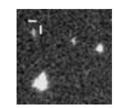
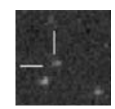
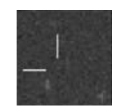
No.	Site*	Date	α	δ	Filter**	m***	Ref****	Interpretation	Discovery frame	Reference frame*****
51	B	2011-12-31.50	02 19 12.06	+46 55 50.2	C	15.5	[277]			
52	T	2012-01-03.87	10 37 17.83	+50 59 34.2	C	19.2	[277]	PSN		
53	B	2012-01-05.53	05 08 06.84	+71 23 52.0	C	15.3	[277]	Dwarf nova		
54	B	2012-01-08.53	03 28 53.57	28 40 45.8	C	15.3	[279]	Red dwarf with high proper motion		
55	T	2012-01-03.96	13 58 27.77	13 56 30.0	C	18.8	[279]	PSN or VS		
56	T	2012-01-04.94	14 08 59.07	25 50 12.0	C	17.0	[279]	Dwarf nova (?)		
57	B	2012-01-08.50	00 34 30.79	30 24 06.3	C	16.0 ± 0.3	[280]	PSN in PGC 002065		
58	K	2012-01-14.86	06 14 31.44	41 59 04.4	C	18.4	[281]	Flare of very weak dwarf nova (23^m)		
59	K	2012-01-13.87	01 39 02.45	61 30 55.6	C	17.1	[282]	Red dwarf with high proper motion		
60	T	2012-01-15.97	16 17 55.05	56 35 52.6	C	18.4	[282]	PSN		

Table 13. (Contd.)

No.	Site*	Date	α	δ	Filter**	m***	Ref****	Interpretation	Discovery frame	Reference frame*****
61	T	2012-01-18.57	04 08 21.91	14 15 15.0	C	17.4	[282]	Cataclysmic variable		
62	K	2012-01-19.72	03 51 35.98	16 26 06.2	C	18.1	[283]	PSN		
63	K	2012-01-19.68	03 41 31.75	14 43 33.9	C	18.3	[283]	(?)		
64	K	2012-01-19.68	07 37 21.02	85 43 23.7	C	18.7	[283]	(?)		
65	K	2012-01-19.66	03 43 37.42	16 43 29.4	C	18.4	[283]	PSN		
66	K	2012-01-20.83	06 31 13.68	34 17 15.5	C	19.4	[283]	PSN		
67	K	2012-01-21.05	12 48 19.37	07 20 49.6	C	16.8	[283]	Cataclysmic variable SDSS J124819+072049		
68	K	2012-01-21.79	04 08 21.86	14 15 16.1	C	18.0	[283]	Cataclysmic variable		
69	K	2012-01-21.78	04 13 52.74	17 03 48.3	C	17.6	[283]	PSN		

* The observatories in the MASTER network that carried out these observations are denoted K—Kislovodsk, U—Ural (Kourov), T—Tunka, B—Blagoveshchensk.
** C—white light (clear).
*** Magnitude with uncertainty $\sigma = \pm 0.1^m$ if not otherwise noted.
**** Reference to ATel telegram.
***** There is a reference to a better quality image in the corresponding ATel telegram.

Table 14. Variable stars in NGC 7129 discovered using Ural MASTER

Star	Type*	Magnitude		Filter	Period, d	Sp****
		max**	min***			
2MASS 21442961+6548438	EA:	14.73, 14.38	15.11, 14.72	R, I		
2MASS 21433767+6550489	INT:	17.84, 16.92, 15.96	18.34, 17.67, 16.72	V, R, I		
2MASS 21435283+6554277	SR:	14.17, 12.77, 11.20	14.30, 12.89, 11.24	V, R, I	23.05:	
2MASS 21412361+6555377	SR:	13.05	13.41	R		
2MASS 21422105+6555405	SR:	14.4	14.55	R		
2MASS 21430782+6557095	I:	13.26	13.5	I		
2MASS 21421203+6600254	INT:	16.51, 15.62, 14.86	17.38, 16.48, 15.39	V, R, I		
2MASS 21405762+6602255	SR:	13.78, 12.29, 10.27	14.11, 12.56, 10.41	V, R, I		
2MASS 21405096+6603475	SR:	12.30, 10.85	12.45, 10.97	V, R		
2MASS 21395519+6604069	EW	15.05, 14.09	15.15, 14.22	V, I	0.887	
2MASS 21425961+6604338	INT	15.17	15.94	I	4.4:	K2
2MASS 21440634+6604231	INT:	16.90, 16.06, 14.78	18.73, 17.38, 16.10	V, R, I		
2MASS 21424705+6604578	BY:	15.16, 14.27, 13.36	15.46, 14.50, 13.50	V, R, I	1.127	
2MASS 21431683+6605486	IN:	15.79	16.01	I		
2MASS 21430188+6606447	INT:	14.89	15.11	I		
2MASS 21425261+6606572	INT	15.66	16.1	I		
2MASS 21425349+6608053	IN:	16.17, 14.89	16.41, 15.07	R, I		
2MASS 21433182+6608506	INT	17.59, 16.73, 15.70	18.65, 17.83, 16.38	V, R, I		
2MASS 21431161+6609114	INT	16.28, 15.21, 14.10	16.53, 15.47, 14.26	V, R, I	1.70:	
2MASS 21432695+6609365	IN:	14.89	14.99	I		
2MASS 21432290+6610000	LB:	15.57	16.11	I		
2MASS 21433625+6611329	BY:	13.43, 12.83, 12.41	13.57, 12.96, 12.51	V, R, I	3.770	
2MASS 21424283+6612282	EB	14.49, 13.63, 12.82	14.74, 13.89, 13.04	V, R, I	1.264	
2MASS 21424023+6613287	INT:	15.54	16.8	I		
2MASS 21413315+6622204	INT	15.18, 14.37, 13.17	15.93, 14.94, 13.63	V, R, I		K4
2MASS 21403066+6626034	LB:	14.85, 13.08, 10.93	14.97, 13.20, 10.99	V, R, I		
2MASS 21402965+6626442	INT:	16.44, 15.45	16.79, 15.64	R, I		
2MASS 21444647+6627018	SR:	13.32, 10.32	13.44, 10.39	V, I		

* The notation for variable types is EA—eclipsing Algol, INT—T Tauri Orion variable, SR—semi-regular variable, I—irregular variable, EW—eclipsing W Ursa Majoris star, BY—BY Draconis variable, LB—slow, irregular, late-type variable, EB—eclipsing β Lyrae variable, RR—RR Lyrae star.
** Maximum magnitudes in the filters given in column (5).
*** Minimum magnitudes in the filters given in column (5).
*** Spectral type.

More detailed algorithms for searches for and preliminary classification of transients have been published in [2].

Searches for slow transients, i.e., unidentified sources that are absent in archival frames of our survey, are well developed. New transients are discovered on a daily basis, and these data are published several times a week in astronomical telegrams (http://www.astronomerstelegram.org/). Table 13 presents a list of transients discovered by the MASTER telescopes.

Let us consider some of the most interesting of these transients in more detail.

3.3.1. The bright supernovae SN2011ha, SN2011gg, SN2011hh, SN2011iq, SN2011ib, SN2011il, SN2011io, SN2011jy, SN2012K. Starting from October 2011, when sufficient archival material had been accumulated for the supernova search to be conducted using the slow-transient

Table 15. Variable stars in NGC 7142 discovered using Ural MASTER

Star	Type*	Magnitude		Filter	Period, d	Sp
		max**	min***			
2MASS 21460307+6543597	SR:	13.55, 12.30, 11.06	13.61, 12.36, 11.10	V, R, I	0.58	
2MASS 21441320+6545013	EB/EW	15.75, 15.15, 15.05	16.20, 15.60, 15.50	V, R, I	0.44	G3
2MASS 21445597+6545499	SR:	15.51, 14.33, 13.75	15.71, 14.53, 13.86	V, R, I	>20	
2MASS 21442843+6546365	EB/EW	17.75, 16.70	18.75, 17.70	V, I	0.33	
2MASS 21434785+6548225	SR:	13.43, 12.16, 11.14	13.47, 12.19, 11.17	V, R, I	0.83	
2MASS 21442961+6548438	EA	14.70, 14.73	15.15, 15.10	R, I	–	F5
2MASS 21451515+6549242	RR:	15.27, 14.77, 14.83	15.37, 14.87, 14.95	V, R, I	0.29	F0
2MASS 21460890+6549318	SR:	13.30, 12.09, 11.30	13.35, 12.13, 11.33	V, R, I	0.54	
2MASS 21435283+6554277	SR:	14.23, 12.80, 11.68	14.35, 12.90, 11.73	V, R, I	0.83	
2MASS 21451069+6554226	SR:	13.09, 11.78, 10.81	13.14, 11.83, 10.84	V, R, I	>20	

* Notation for this and other parameters is the same as in Table 14.

search method, the number of discovered supernovae sharply rose. All these supernovae are very bright, with magnitudes from 15^m to 17^m, making it easy for telescopes with diameters of 1–2 m to obtain spectra. Nevertheless, as can be seen in Table 13, it has not been possible to obtain spectra for all the detected transients, so that many objects unfortunately remain unconfirmed. Spectral confirmation of the supernova candidates among the transients thus remains incomplete.

However, it has been possible to obtain spectra for many of the transients discovered with the MASTER network. This very important task requires correct selection of the parameters of the system, since this is a serious problem for many large-survey telescopes, such as those in the Catalina Sky Survey.

The very bright, Type IIn pec supernovae SN2011ib and distant supernova SN2011ha with a redshift $z \sim 0.1$ stand out in this list. The remaining supernovae have redshifts from 0.01 to 0.05.

3.3.2. Discovery of the transient MASTER-OT082753+704606. The very interesting object MASTER-OT082753+704606 was discovered by the Tunka MASTER telescope during a regular survey, in two passes on March 20, 2011 at 14:09:51 UT and 40 min later [222]. The observations were initially reduced in the search regime [2], i.e., in white light; at the time of discovery, the object had a magnitude of $19.1^m \pm 0.3^m$. The object can be identified with a weak source from GSC2.3 [284] with magnitude $j = 21.7^m$ (N7U 1004894), but is absent from other catalogs (such as USNO B1), and is not detected in other photometric bands. Observations were made by A.V. Moiseev with the Special Astrophysical Observatory (SAO) 6-m telescope using the SCORPIO-2 spectrograph on March 29, 2011 at 19:34:23 [285], yielding a spectrum at 4000–8500 Å with a resolution of 6–7 Å [222]. The spectrum only traces the growing blue continuum and one broad emission line with $\lambda_c = 5320$ Å. This line can most easily be explained as an emission line in the spectrum of a quasar or Seyfert (Sy2) galaxy.

Before March 2012, this region was observed by the MASTER network about once per month. The object is present in all frames with a magnitude of $19.5^m \pm 0.4^m$.

Later, on April 6 and May 14, 2012, ultraviolet and X-ray observations were carried out with SWIFT [239, 286]. The XRT did not detect X-ray emission from the object at the earlier epoch, but a weak object at the 3.5σ level was detected at the later epoch. These observations may also indicate that the object is a super-bright Type II supernova (Type IIn). In this case, the observed emission line can probably be identified as HeII 4686 Å at $z = 0.135$ [286].

New spectral observations are required for a more precise identification of this transient.

Table 16. First observations of asteroid 2011 OH26, found by the search program

Date	α	δ	Magnitude
2011-07-29.92584	$21^h35^m25.72^s$	$12°02'23.5''$	19.1^m
2011-07-29.95519	21 35 24.13	12 02 39.9	18.5
2011-08-02.79100	21 32 09.01	12 34 20.2	19.4
2011-08-02.85025	21 32 05.71	12 34 48.0	18.5

Fig. 17. Transient MASTER-OT081443+125459: discovery frames (left and center) and reference frame (right).

3.3.3. Discovery of the transient MASTER-OT081443+125459. This very bright ($V = 14.8^m$) optical transient was discovered on October 24, 2011 at 18:58:57 UT with the Blagoveshchensk MASTER telescope [256] (Fig. 17). I.D. Karachentsev and T.A. Fatkhullin obtained spectra with the SCORPIO spectrograph on the SAO 6-m telescope on October 28, 2011, for two successive exposures, one in the blue and one in the red, with a resolution of 5 Å [287, 288]. The resulting spectrum is presented in Fig. 18. This spectrum contains Hα and HeII 4685 Å emission and absorption, as well as HeI 5876, 5016, 4920, 4470 Å, Hβ, Hγ, and Hδ absorption. The spectrum is typical of WZ Sge-type dwarf nova [288]. A similar spectrum was obtained independently on the Nordic Optical Telescope [289].

3.3.4. Discovery of the transient MASTER-OT 105123+672528. This interesting, bright transient source with magnitude 14.6^m was discovered at the Blagoveshchensk MASTER telescope on January 1, 2012. It is striking that this object can be identified with the X-ray source 1RXS J105120.5+672550 from the ROSAT catalog [290]. Sokolovskii et al. [276] observed this object over 3.5 h on January 6, 2012, and did not find any optical variability exceeding 0.06^m. A month later, on February 3, 2012, the object was again observed by the Kislovodsk MASTER telescope. By this time, it had returned to its quiesent state with a magnitude of $\sim 18.0^m$. Pavlenko et al. [291] later detected pulsations with period $\sim 0.06^{\mathrm{d}}$ and amplitude 0.4^m in the quiescent state. The hardness of the source in the ROSAT catalog and the optical behavior suggest that this may be a SU UMa-type dwarf nova.

3.4. Observations of Fast Transients

In addition to long transients (flaring on time scales from days to months), MASTER also searches for a completely new class of objects—fast transients—whose flares have durations from seconds to several hours. Physically, these could be

(1) mergers of neutron stars and black holes (NS + NS, NS + BH),

(2) orphan afterglows, which, as a rule, are associated with GRBs whose beams of hard radiation are not directed toward the Earth,

(3) transients of an unknown nature.

Searches for rapidly flaring and decaying transients can be carried out when the same region of sky falls into the fields of view of both tubes. This is the case during observations of GRBs, re-observation of interesting candidates, and photometric observations

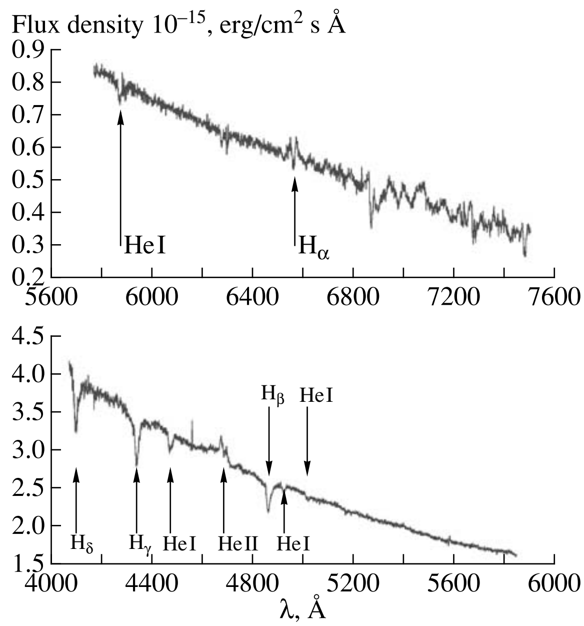


Fig. 18. Spectrum of the transient MASTER-OT081443+125459 obtained using the SCORPIO spectrograph on the SAO 6-m telescope [288].

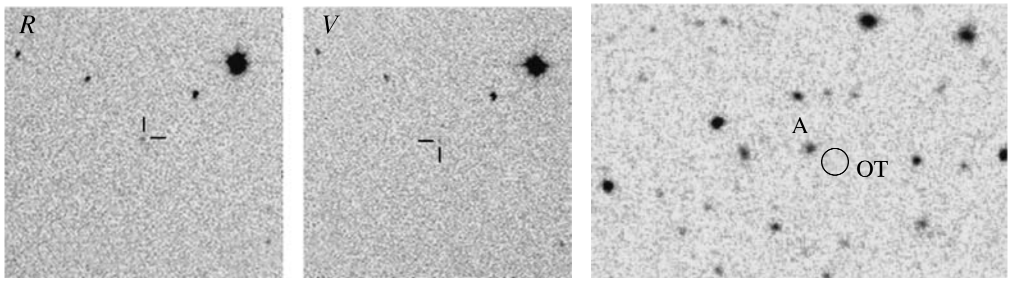


Fig. 19. Discovery frames for the transient MASTER-OT114444+323011 (left and center) and exposure obtained on the SAO 6-m telescope (right) [269]. The letter A in the right panel denotes the galaxy nearest to the transient.

of various objects (such as supernovae or exoplanets). Searches for such objects were begun comparatively recently (from October 2011), and these events are fairly rare. Nevertheless, a number of the discovered objects are worthy of more detailed discussion.

Unfortunately, very often, a short transient event can easily be confused with glare from space debris in a geostationary or geosynchronous orbit. Therefore, each short transient must first be verified using a database of artificial Earth satellites. The main complication with this is the long time exposures for the MASTER observations (usually 180 s). Satellites move large distances over such times (a geostationary satellite will cover $\sim 1°$, and satellites with lower orbits even more); therefore, the search must be carried out by recalculating the orbital grouping during the exposure many (2000–3000) times, approximating the motion of a satellite by a straight line segment corresponding to a short section of its orbit, and computing the minimum distance from the object to the calculated orbital segment. Further, to account for uncataloged satellites, similar unidentified objects lying along a single line are searched for in the frame. If three or more such unidentified objects lying along a line are found, the object is excluded from consideration.

3.4.1. Discovery of the transient MASTER-OT114444+323011. A synchronous flare in both tubes and in both photometric bands (R and V) was detected on December 11, 2011 at 21:06:07.2 during a regular survey observation. The object is visible in the same place in both images, and with good signal-to-noise ($S/N = 7.6\sigma$; Fig. 19). Its magnitude is $\sim 16.5^m$, but the object is not found on frames taken 4 min earlier and 41 min later, with optical limits $M_R > 17.9$ and $M_V > 17.4$. We verified that no asteroids, planets or artificial Earth satellites were present in this location. A.V. Moiseev obtained a deep SCORPIO-2 exposure of the object on the SAO 6-m telescope on December 23, 2011 (Fig. 19, right), obtaining the limit $R_C > 25^m$ [269]. Unfortunately, no weak galaxies or other sources were found inside our error box. The nearest galaxy is $6.2''$ from the center of the error box, corresponding to a linear distance of 45 kpc, assuming a redshift $z = 1$, typical for a 23^m galaxy ($\Omega_\lambda = 0.7$, $H_0 = 75$ km s^{-1}Mpc^{-1}). The nearest event associated with a GRB was an AGILE trigger an hour later; no GRBs were detected by Swift, Fermi, INTEGRAL, or Wind-KONUS at this time.

3.4.2. Discovery of the transient MASTER-OT103630-003523. This rapid transient was discovered on December 30, 2011 at 00:33:24.715, also synchronously in both tubes. Both images were obtained in white light. The magnitude of the source is $18.4^m \pm 0.2^m$ in both frames; both frames have a limiting magnitude of 20.4^m, indicating a signal-to-noise ratio $S/N = 10$. The same region was observed during the first pass a half hour earlier, with a limiting magnitude of 20.4^m, indicating that the object flared by at least 2^m. As in the previous case, we verified the absence of satellites, asteroids, and GRBs registered by Swift, Fermi, INTEGRAL, and Wind-KONUS in this region at the time of our observations.

The region was re-observed ~ 6.3 days after our detection with the GROND telescope [292] simultaneously in the $g'r'i'zJHK$ filters. No optical candidate was detected in any of these filters with very strong limits [274] (the limit for the filter closest to the MASTER photometric band was $g' > 24.7$). Greiner et al. [292] note that a rapid flare (over 30 min) and fairly rapid decay (6^m over six days) are typical for GRB afterglows and flares on M dwarfs.

3.5. Photometric Studies of Variable Stars and Exoplanets

Observations of the open clusters NGC 7129 and NGC 7142 were carried out during 2010 at the MASTER telescope installed at the Kourov Astronomical Observatory of the Ural Federal University.

NGC 7129 is a region of active star formation consisting of a young open cluster that is immersed in a gas–dust nebula. Herbig–Haro (HH) objects [293], water masers, T Tauri stars, and Ae/Be Herbig stars

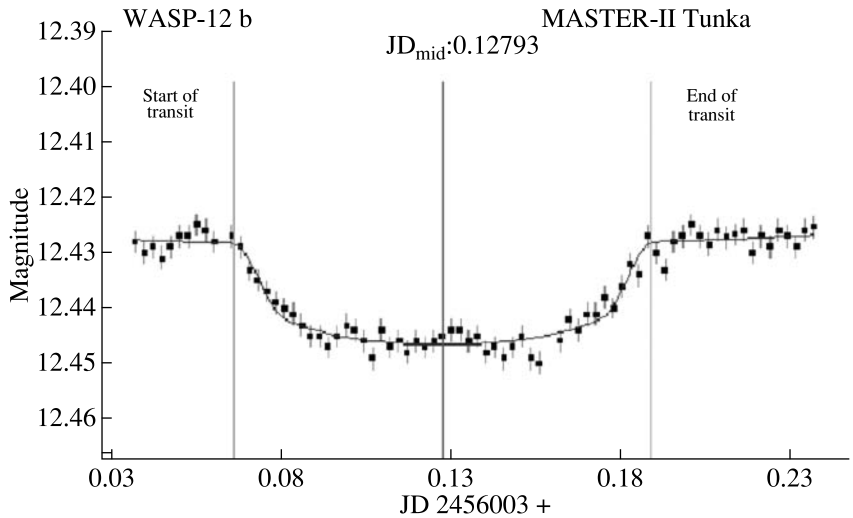


Fig. 20. Light curve of the exoplanet transit WASP-12b in the R filter obtained on March 16, 2012.

are observed in the cluster [294, 295]. According to AAVSO data, a $75' \times 45'$ region around the cluster contains six variable stars.

NGC 7142 is one of the oldest known open clusters. According to AAVSO data, a $30' \times 30'$ region around the center of the cluster contains one known and one suspected variable star.

About 500 frames with exposures of 120 s were taken in the I and V filters, and about 150 frames with exposures of 60 s in the R filter. The preliminary reduction and aperture photometry of the frames obtained were carried out using the IRAF V2.14 package. The magnitude uncertainties for stars with magnitudes from 11^m to 16^m were from 0.007^m to 0.07^m.

A C++ program designed to search for variable stars was written, realizing a modification of the algorithm described in [296].

About 4000 stars were searched for variability, resulting in the discovery of variability in 24 stars in the field of NGC 7129 (Table 14) and in 11 stars in the field of NGC 7142 (Table 15). The symbol ":" in these tables denotes a preliminary value for the corresponding parameter, which may be refined in future.

3.5.1. Observations of exoplanets. About 777 exoplanets orbiting other stars had been discovered by the middle of 2012, 239 of them through transit observations [297]. In the case of transiting exoplanets, the star, exoplanet, and observer are positioned such that an observer on Earth will periodically observe both a passage of the exoplanet across the stellar disk and an eclipse of the planet by the star.

More than half of known transiting exoplanets display deep transit depths of more than 0.01^m, making them accessible for further studies with ground telescopes.

Observations of exoplanet transits can be used to estimate the radii and orbital inclinations of exoplanets, and also to detect the presence of perturbing bodies in the system (other exoplanets or their satellites), from variations in the transit times and their durations. The theoretical basis for such analyses is given in [298–301].

For characteristic transit depths of about 0.01^m, reliable detection of a transit, determination of its duration and the transit mid-time, and detection of fine transit effects (such as brightness fluctuations during a transit) requires a photometric accuracy of about 0.001^m, which is achievable in observations with the MASTER telescopes.

Regular observations of exoplanet transits began in September 2011 using the Tunka and Ural MASTER telescopes.

The Exoplanet Orbit Database and Exoplanet Data Explorer service were used to obtain an initial sample of exoplanets with transit depths of no less than 0.01^m, orbital periods of no more than several days, and transit durations of no more than three-to-four hours [302]. The final list of stars for these observations was composed of objects believed to display variations in their transit depths, transit durations, and times of transit, as well as objects showing evidence of fine transit effects.

Observations of the known transiting exoplanets TrES-3b, WASP-10b, HAT-P-10b/WASP-11b, WASP-12b, WASP-33b, and HAT-P-36b were obtained from September 2011 through May 2012. In

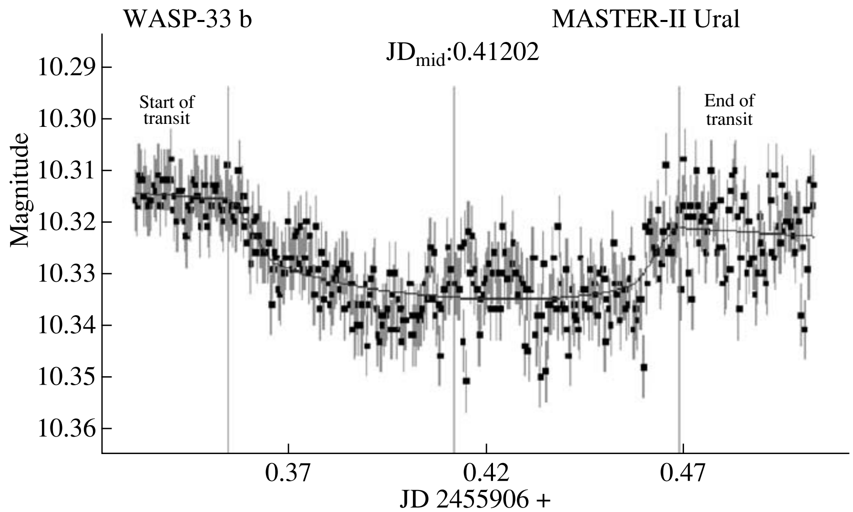


Fig. 21. Light curve of the exoplanet transit WASP-33b in the R filter obtained on December 10, 2012.

all, 16 light curves were derived, which have been published in the Exoplanet Transit Database.

Corrections for the dark current, flat-fielding, and the aperture photometry were carried out in the IRAF package. Correction of the data for variable atmospheric opacity was applied using the Astrokit software developed at the Kourov Astronomical Observatory, which realizes a modification of the algorithm of Everett and Howell [303].

The transit of WASP-12b on March 16, 2012 observed with the Tunka MASTER telescope in the R filter is presented as an example (Fig. 20). The model curve was obtained using the "Model-fit your data" service of the Exoplanet Transit Database. The standard deviation of brightness variations of the control star USNO–A2.0 1125–04085646 is 0.004^m.

WASP-12 is a classical "star + hot Jupiter" exoplanet system located in the constellation Auriga. The central star is a sun-like star with a mass about 35% greater than a solar mass and spectral type G0. A gas giant with a mass about 40% greater than a Jupiter mass revolves around this star in a nearly circular orbit with a period slightly longer than an Earth day. The main peculiarity of the sytem is the very low orbit of the planet—currently the lowest of all known exoplanets. This system also displays variations in the transit time, making it of interest for further studies.

The presence of fine transit effects is illustrated by the transiting exoplanet WASP-33b, which was observed by the Ural MASTER telescope on December 10, 2012 (Fig. 21). The photometric accuracy was estimated using the standard deviation of brightness variations displayed in the R filter by the control star, BD+37 553, equal to 0.007^m. However, even with such moderate accuracy, a characteristic increase in the brightness of the central star in the middle of the transit can be seen. According to the Exoplanet Transit Database, such an increase in brightness during transit has periodically been noted by other observers as well.

In the most recent publication concerning the WASP-33 exoplanet system, Kovács et al. [304] suggest that the increase in brightness just after the center of the transit can be explained by the presence of a large spot on the stellar surface, which is strongly inclined to the orbital plane of WASP-33b.

Understanding the nature of fine transit effects requires further observations; however, the good quality of currently available data already makes it possible to draw some conclusions about the physical origin of these effects with high probability. Note that some solar flares develop on similar time scales. Brightness variations could also be a result of eclipsing of spotted or facular fields by a planet. Work in this area is ongoing.

3.6. Observations of Small Bodies in the Solar System

3.6.1. Discovery of asteroids 2011 OH26 and 2011 WR28. On August 2, 2011, soon after the registration of the Kislovodsk MASTER observatory at the Minor Planet Center (MPC), the moving-object search system discovered a 19^m asteroid candidate with coordinates $21^h32^m09.01^s$ and $+12°34'20.2''$ moving with a mean velocity of $-35''$/hr in right ascension and $18''$/hr in declination. The FWHM of the object in various frames was from two to four pixels. Four objects were made of this object, listed in Table 16.

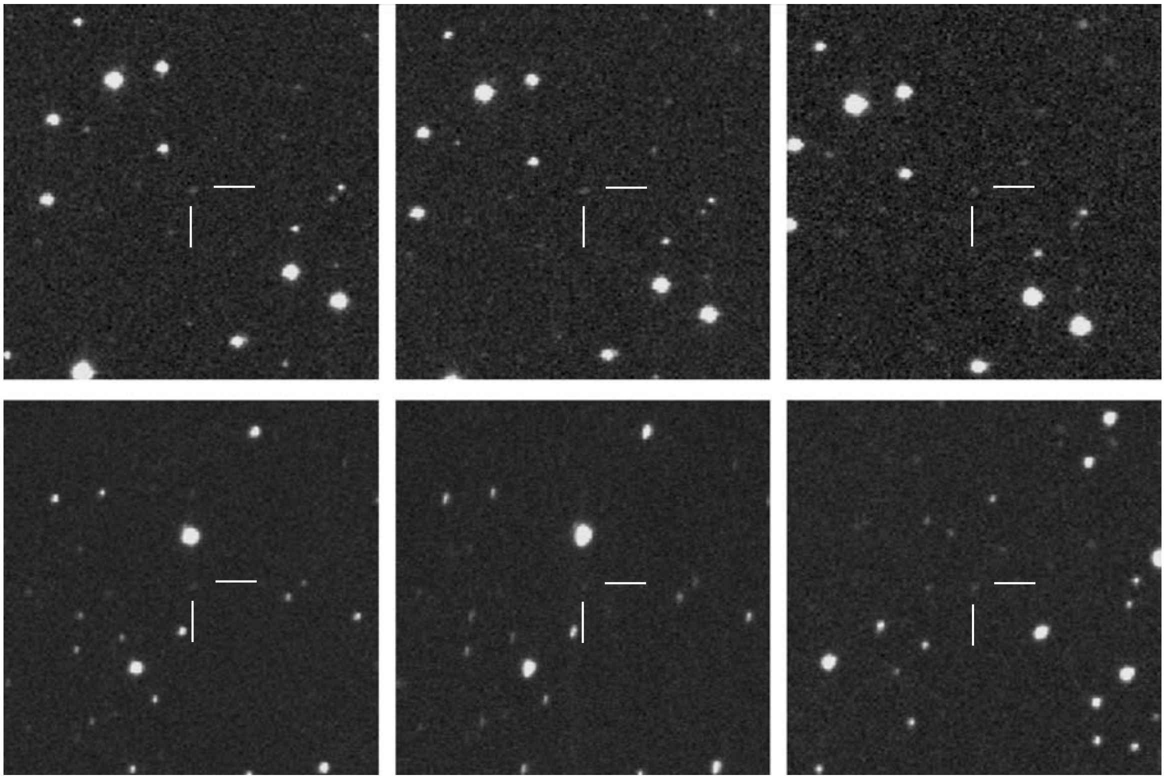


Fig. 22. Images of asteroid 2011 WR28. The upper row shows the first images from observations on November 20, 2011, and the lower row images obtained on November 21 and 22, 2011.

That same day, the search program identified another four asteroid candidates, which proved to be observations of this same object. Many observations overlapped each other. These five candidates were yielded by seven observations of the object. A telegram about these observations was sent to the MPC, suggesting this was a new discovery. The new object was confirmed by the F51 Observatory (Pan-STARRS survey) on August 3, 2011, based on a third of an observing night. The new asteroid was named 2011 OH26. This discovery made it possible to debug the required search programs and services. It was decided to automate all computations that had been carried out by hand during observations of the asteroid.

The search program identified another $\approx 18.5^m$ asteroid candidate on November 20, 2011, moving with a velocity $-38.536''$/hr in right ascension and $23.503''$/hr in declination. Three observations of the object were made. Its FWHM was about five pixels. The next day, two more observations before November 21, 2011 were found using a linear search algorithm. A third set of images was obtained in November 22, 2011. About ten images were obtained in all, six of which are presented in Fig. 22. Based on these results, two telegrams were sent to the MPC. After observations had been obtained on three nights, the MPC assigned the object the temporary name 2011 WR28.

All the MASTER observatories are now registered with the MPC. Observations of all real asteroids have been sent to the MPC automatically on a weekly basis since January 20, 2012. New asteroid candidates are found at the Kislovodsk and Tunka observatories on virtually every Moonless night.

Note that the MASTER network was not originally designed for asteroid searches. By virtue of the way in which the survey observations are conducted (two passes separated by 45 min), numerous observations of known asteroids are automatically obtained during normal sky-survey observations. However, because the firm identification of new asteroids requires a minimum of three observations of the same area, it is possible to discover new asteroids only in fields that have been re-observed more than twice in five to seven days, e.g., during alert observations, photometry of supernovae and blazars, and in the case of multiple observations of transient objects discovered by MASTER. Note also that the creation of a single network database makes it possible to increase the number of observations that can be considered (it enables working with observations from all observatories), thereby making it possible to increase the number of discovered objects.

Table 17. First observations of comet C/2012 A2 with the MASTER network

Date	α	δ	Magnitude	MASTER Observatory
2012-01-15.94094	$12^h53^m13.01^s$	$42°26'45.4''$	17.4	MASTER-Tunka
2012-01-15.97258	12 53 12.60	42 27 25.3	17.5	Tunka
2012-01-16.68987	12 53 12.60	42 27 25.3	17.5	Tunka
2012-01-16.63242	12 53 02.86	42 41 15.0	(?)	Blagoveshchensk
2012-01-16.65740	12 53 02.10	42 41 44.1	(?)	Blagoveshchensk
2012-01-16.67166	12 53 02.23	42 42 08.2	18.7	Blagoveshchensk
2012-01-16.68635	12 53 01.86	42 42 27.7	(?)	Blagoveshchensk

Table 18. Observations of comet P/2010 H2 (Vales)

Date	α	δ	Magnitude*	Observatory
2010-04-15.40	–	–	$V > 20^m$	Catalina Sky Survey
2010-04-15.63	–	–	$C > 16^m$	MASTER-Blagoveshchensk
2010-04-15.82	$13^h39^m33.68^s$	$04°45'41.4''$	$V = 13.7^m \pm 0.1^m$	MASTER-Kislovodsk
2010-04-16.01	13 39 25.17	04 45 49.5	$C = 12.6^m$	Črni Vrh (Slovenia) [306]

* C—white light (clear).

3.7. Independent Discovery of the Comet C/2012 A2 (LINEAR)

The transient-search program discovered a comet-like object on January 15, 2012 [305]. At that time, the Tunka MASTER observatory, which made this discovery, had only just passed through the procedure for registration with the MPC, and the observations of this comet were accepted to the MPC with a delay of several days. This comet was discovered at other observatories slightly later, and it was these who have become the official discoverers of the comet. The first observations are presented in Table 17. A video recording of the observations can be found at the site www.observ.pereplet.ru/images/possible_comet 2012a/comet.gif.

3.7.1. Observations of the Comet P/2010 H2 (Vales). The Črni Vrh Observatory (Slovenia) detected a flare of comet P/2010 H2 on April 16, 2010. This same region was observed in a automated regime during MASTER and Catalina surveys. MASTER and Catalina observations on April 15, 2010 enable determination of the time when the comet flared with an accuracy to within several hours. The region containing the comet was observed by chance at 13:20 during a regular survey at the Blagoveshchensk observatory; the object was not detected on this frame, which had a limiting magnitude of 16^m. The same region was observed in a regular survey regime by the Kislovodsk MASTER telescope four hours later, at 19:44 UT; these frames showed a bright object slightly brighter than 14^m in the V filter. These observations became the first observations of this flare in the world (Table 18).

4. CONCLUSION

Observations and transient searches using the MASTER telescope network are ongoing. It is planned to transform MASTER into a global network, and to begin regular observations of the Southern sky using observatories on the Canary Islands, Argentina, and in other countries. Work on the creation of a single MASTER database is being carried out at the Sternberg Astronomical Institute. This database will enable unified data analyses and searches for optical transients based on observations at all the network telescopes. All the tools required to search for and analyze optical transients, supernovae, asteroids, and variable stars based on both archival and new images will be collected in the database. An archive of images obtained by the MASTER telescopes since 2003 will be established, with each user being issued a personal password. An invitation is extended to all those interested in collaboration; requests for registration can be submitted at the site http://master.sai.msu.ru/db/.

APPENDIX

TABLE OF OBSERVATIONS OF SUPERNOVAE WITH THE MASTER NETWORK

Statistics of images of supernovae obtained with the robotic telescopes of the MASTER network (January 2009–June 2011). If a supernova is present in frames preceding the moment of discovery, it is marked with an asterisk (*). A detailed version of the table with data for each observation can be found at http://master.sai.msu.ru/static/SN/sn_observations.html

No.	Name	Magnitude	Date and time	Number of frames	Date and time of first frame	Date and time of last frame
1	2009L	16.8	2009-01-13 12:58	8	2009-01-19 02:26	2009-01-23 02:34
2	2009av	18.6	2009-03-02 14:23	2	2009-05-19 18:45	2009-05-19 20:17
3	2009ay	16.4	2009-03-20 17:48	4	2009-05-02 19:50	2009-05-02 20:25
4	2009ba	18.4	2009-03-21 09:59	2	2009-04-13 18:33	2009-04-13 19:04
5	2009bf	17.8	2009-03-17 12:06	42	2009-04-10 20:36	2009-04-23 18:32
6	2009bn	18.9	2009-02-27 14:12	1	2009-04-13 21:54	2009-04-13 21:54
7	2009bo	18.9	2009-03-17 12:27	20	2009-04-13 20:40	2009-04-23 18:26
8	2009bp	17.6	2009-03-17 14:07	12	2009-04-10 22:42	2009-04-15 22:11
9	2009bv	18.1	2009-03-27 13:07	12	2009-04-11 21:01	2009-05-10 18:16
10	2009bz	16.8	2009-03-29 15:19	42	2009-04-10 23:32	2009-05-11 20:59
11	2009cr	18.0	2009-03-25 11:18	6	2009-04-10 20:11	2009-04-15 19:35
12	2009cz	17.9	2009-04-06 09:15	10	2009-04-09 17:52	2009-04-12 17:42
13	2009db	18.4	2009-03-19 14:21	6	2009-04-15 21:57	2009-04-21 21:02
14	2009dc	16.5	2009-04-09 15:51	57	2009-04-26 21:05	2009-05-19 19:34
15	2009dj	19.1	2009-03-24 13:58	9	2009-05-12 19:54	2009-05-12 20:58
16	2009ds	16.8	2009-04-28 11:49	1	2009-05-20 19:00	2009-05-20 19:00
17	2009dw	19.2	2009-04-21 13:36	10	2009-05-11 19:25	2009-05-12 20:48
18	2009dy	18.4	2009-04-22 15:01	8	2009-05-10 19:54	2009-05-12 21:05
19	2009ea	18.1	2009-04-03 14:47	1	2009-05-22 19:41	2009-05-22 19:41
20	2009eb*	17.7	2009-04-17 09:54	2	2009-04-13 18:33	2009-04-13 19:05
21	2009ec*	18.3	2009-04-19 11:06	2	2009-04-13 18:47	2009-04-13 19:19
22	2009eg	17.6	2009-03-31 14:54	2	2009-05-13 19:10	2009-05-18 20:52
23	2009en	17.6	2009-05-08 14:46	1	2009-05-22 19:38	2009-05-22 19:38
24	2009es	17.7	2009-05-24 23:59	2	2009-08-12 19:21	2009-08-12 19:21
25	2009fv	16.3	2009-06-02 16:29	1	2009-08-26 16:39	2009-08-26 16:39
26	2009fy	16.1	2009-06-01 23:24	23	2009-08-15 18:31	2009-08-28 20:33
27	2009ga	16.2	2009-06-08 23:28	3	2009-07-29 21:41	2009-09-01 19:58
28	2009gk	18.3	2009-06-23 21:44	7	2009-08-12 19:11	2009-08-12 22:25
29	2009gq	18.3	2009-06-02 22:14	1	2009-08-18 21:23	2009-08-18 21:23
30	2009ha	16.5	2009-07-02 02:37	32	2009-08-13 00:12	2009-08-23 22:53
31	2009he	17.5	2009-07-03 16:22	1	2009-09-07 16:35	2009-09-07 16:35
32	2009hf	17.2	2009-07-09 00:37	13	2009-08-13 00:01	2009-08-28 23:08
33	2009hh	16.1	2009-07-10 03:20	2	2009-08-28 00:49	2009-08-28 01:38
34	2009hi	18.0	2009-07-10 23:23	11	2009-08-18 19:54	2009-09-08 21:23
35	2009hj	19.1	2009-06-26 22:45	13	2009-08-14 18:44	2009-08-15 20:10
36	2009hl	18.0	2009-07-11 17:31	15	2009-08-04 18:47	2009-10-07 14:43
37	2009hn	17.5	2009-07-24 02:32	29	2009-08-12 23:46	2009-08-27 23:56
38	2009ho	18.4	2009-07-25 02:28	6	2009-08-27 20:04	2009-10-17 22:55
39	2009hp	16.7	2009-07-26 02:58	2	2009-08-26 01:26	2009-09-29 21:09

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42	2009hv	18.6	2009-06-25 14:54	2	2009-08-14 17:58	2009-08-14 18:01
43	2009hw	18.6	2009-07-17 19:20	2	2009-08-21 18:30	2009-08-29 17:49
44	2009hy	18.7	2009-08-02 22:16	32	2009-08-12 19:15	2009-10-21 16:10
45	2009hz	17.8	2009-08-03 19:56	2	2009-08-15 18:58	2009-08-15 18:58
46	2009ic	14.8	2009-08-05 04:53	14	2009-08-18 01:05	2009-09-19 23:55
47	2009ie	19.3	2009-07-24 02:48	3	2009-08-27 20:36	2009-10-14 23:19
48	2009ig	17.5	2009-08-20 02:38	7	2009-08-27 23:11	2009-09-26 19:51
49	2009ih	17.3	2009-08-21 15:55	3	2009-09-14 16:02	2009-09-23 15:01
50	2009ii	18.5	2009-08-21 07:01	2	2009-08-27 23:20	2009-08-28 00:08
51	2009im	15.6	2009-08-24 03:33	9	2009-09-17 21:11	2009-09-29 21:16
52	2009in	16.5	2009-08-25 23:22	6	2009-09-14 18:24	2009-09-29 19:30
53	2009io	18.9	2009-08-13 21:02	5	2009-10-09 15:58	2009-11-09 15:38
54	2009iq	18.1	2009-08-13 02:50	4	2009-08-28 23:32	2009-10-25 21:40
55	2009is	16.4	2009-07-30 02:57	4	2009-09-17 17:13	2009-09-17 18:14
56	2009iv	17.6	2009-08-21 02:58	16	2009-08-21 23:08	2009-10-03 19:26
57	2009ix	18.1	2009-09-08 03:17	30	2009-08-27 23:21	2009-11-27 20:28
58	2009iz*	18.2	2009-09-19 02:42	21	2009-09-17 22:01	2009-11-16 19:48
59	2009ja	18.6	2009-08-30 23:02	2	2009-10-17 18:10	2009-10-17 18:10
60	2009jb	17.4	2009-09-17 17:23	2	2009-10-04 15:33	2009-10-09 15:44
61	2009jc	18.2	2009-09-17 01:02	4	2009-10-18 20:29	2009-10-21 19:09
62	2009jd	18.4	2009-09-19 00:29	3	2009-10-19 21:39	2009-10-23 18:47
63	2009je	17.8	2009-09-17 05:28	13	2009-10-04 21:51	2009-10-25 20:56
64	2009jf	18.0	2009-09-27 23:04	12	2009-10-12 14:54	2009-12-04 15:31
65	2009jg	15.8	2009-09-22 17:40	1	2009-10-04 15:39	2009-10-04 15:39
66	2009jp	17.6	2009-10-09 23:17	18	2009-09-26 19:38	2009-12-03 16:18
67	2009jq	17.9	2009-10-09 02:27	38	2009-09-26 22:41	2009-11-23 14:21
68	2009jr*	16.0	2009-10-08 20:26	42	2009-10-08 16:07	2009-11-26 09:18
69	2009js	17.2	2009-10-11 02:25	16	2009-10-23 17:44	2009-11-23 14:58
70	2009jt	18.6	2009-09-29 03:41	6	2009-10-19 20:14	2009-11-13 19:47
71	2009ju	18.2	2009-10-11 05:18	6	2009-10-24 20:44	2009-11-16 00:31
72	2009jw	18.3	2009-10-03 07:37	9	2009-10-23 20:22	2009-11-13 19:50
73	2009jx	17.3	2009-10-17 21:12	4	2009-10-23 17:55	2009-11-28 15:51
74	2009ka	17.5	2009-10-18 21:17	7	2009-10-28 17:26	2009-11-24 14:49
75	2009kk*	15.5	2009-10-15 03:49	28	2009-10-14 00:20	2009-11-26 16:47
76	2009km	16.5	2009-10-23 03:03	20	2009-11-10 21:23	2009-12-09 19:09
77	2009kn	16.6	2009-10-26 08:09	22	2009-11-11 03:08	2009-12-08 23:52
78	2009ko	16.6	2009-10-28 08:02	21	2009-10-15 01:23	2009-12-16 22:50
79	2009kq	18.5	2009-11-05 08:36	6	2009-11-24 20:56	2009-12-25 19:15
80	2009kr	16.0	2009-11-06 05:12	15	2009-11-24 20:59	2009-12-25 19:11
81	2009lb	17.3	2009-11-12 04:04	57	2009-11-23 15:11	2010-01-10 13:10
82	2009ld	18.5	2009-11-05 22:49	4	2009-11-17 15:48	2009-12-04 15:35

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85	2009lh	17.7	2009-11-16 09:53	8	2009-11-25 02:17	2009-12-26 00:44
86	2009li*	18.0	2009-11-16 00:22	9	2009-11-08 18:05	2009-12-09 17:35
87	2009lj	19.0	2009-11-13 03:12	1	2009-11-16 20:12	2009-11-16 20:12
88	2009lk	17.8	2009-11-17 01:57	25	2009-11-24 14:57	2010-01-05 15:28
89	2009lm	18.5	2009-11-17 09:43	6	2009-12-19 02:53	2009-12-25 22:39
90	2009ln	18.2	2009-11-18 03:07	16	2009-11-24 15:22	2010-01-07 15:31
91	2009lo	18.2	2009-11-20 01:09	10	2009-11-08 19:11	2010-01-02 17:22
92	2009lr	17.3	2009-11-23 23:14	17	2009-12-02 17:54	2010-01-03 16:10
93	2009ls	15.1	2009-11-23 10:51	19	2009-11-17 01:43	2010-02-03 17:28
94	2009lu	18.0	2009-11-20 10:54	4	2009-12-19 02:02	2010-01-09 00:31
95	2009lv*	17.4	2009-11-19 00:16	22	2009-11-17 16:00	2010-01-12 10:09
96	2009lw	18.8	2009-11-24 02:28	13	2009-11-16 17:33	2010-01-07 15:27
97	2009lx	17.1	2009-11-24 11:40	8	2009-12-18 01:40	2010-01-09 00:23
98	2009ly	19.0	2009-11-06 00:41	4	2009-12-09 17:40	2009-12-10 18:24
99	2009mb	19.0	2009-10-18 09:11	5	2009-11-16 02:31	2010-01-08 23:27
100	2009mc	18.1	2009-11-21 08:56	20	2009-12-16 22:26	2010-01-09 01:26
101	2009md	16.5	2009-12-04 10:48	15	2009-12-16 22:38	2010-02-23 19:12
102	2009me	18.1	2009-12-03 12:09	8	2009-12-08 21:46	2010-02-01 21:14
103	2009mf	16.2	2009-12-06 01:00	84	2009-12-16 12:53	2010-01-25 09:09
104	2009mh*	16.6	2009-12-12 11:43	23	2009-12-02 03:31	2010-03-11 15:55
105	2009mi	15.4	2009-12-12 05:52	9	2009-12-18 21:05	2010-01-18 19:29
106	2009mj	17.8	2009-12-10 06:53	21	2009-12-16 15:59	2010-02-26 16:17
107	2009mt	17.1	2009-11-25 04:03	11	2009-12-25 16:34	2010-01-12 13:05
108	2009mv*	17.4	2009-12-16 07:15	56	2009-12-15 14:38	2010-02-27 18:46
109	2009mx*	18.3	2009-12-24 09:20	20	2009-12-23 18:42	2010-03-23 19:01
110	2009my	17.8	2009-12-24 11:10	12	2010-01-09 00:57	2010-02-09 22:06
111	2009mz	15.1	2009-12-26 14:03	14	2010-01-05 01:12	2010-02-11 02:02
112	2009na	15.3	2009-12-26 10:47	88	2009-12-14 19:20	2010-02-14 23:04
113	2009ne	18.6	2009-11-10 12:07	14	2009-12-01 01:26	2010-02-07 00:41
114	2009nh*	19.3	2009-11-26 09:11	9	2009-11-25 00:26	2010-02-02 22:03
115	2009ni	18.4	2009-12-16 08:44	9	2010-01-05 22:11	2010-02-03 22:53
116	2009nj	18.8	2009-12-17 11:06	1	2010-02-03 00:44	2010-02-03 00:44
117	2009nk	17.0	2009-12-29 14:11	19	2009-12-19 03:37	2010-03-27 23:16
118	2009nn	17.3	2009-12-05 12:33	11	2010-01-20 02:02	2010-02-26 22:57
119	2009no	17.3	2009-12-27 12:51	81	2010-01-18 20:52	2010-03-26 21:05
120	2009np	18.0	2009-12-15 12:27	13	2010-01-09 00:27	2010-02-23 23:28
121	2009nq	16.2	2009-12-28 23:15	24	2010-01-09 11:47	2010-02-06 16:23
122	2009nr	13.6	2009-12-22 13:11	195	2009-12-22 21:38	2010-03-20 22:42
123	2009nu	18.7	2009-12-15 02:20	6	2010-02-01 16:34	2010-02-02 17:31
124	2009nv	19.1	2009-12-18 12:02	8	2009-12-24 01:34	2010-02-24 23:40
125	2009nx	19.0	2009-12-20 00:44	10	2010-02-01 16:44	2010-02-06 16:20

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No.	Name	Magnitude	Date and time	Number of frames	Date and time of first frame	Date and time of last frame
126	2010A	16.0	2010-01-04 02:32	69	2010-01-09 16:24	2010-02-16 16:16
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128	2010C	18.8	2010-01-10 10:51	12	2010-02-03 22:38	2010-03-19 18:59
129	2010D	17.0	2010-01-10 10:31	11	2010-01-16 17:11	2010-02-22 15:28
130	2010H	15.3	2010-01-16 08:06	43	2010-01-14 13:48	2010-03-28 11:49
131	2010I	18.1	2010-01-08 10:12	23	2010-02-03 23:33	2010-03-20 22:01
132	2010K	16.4	2010-01-08 12:02	54	2010-01-22 17:54	2010-02-25 23:09
133	2010L	18.5	2010-01-12 02:23	13	2010-02-01 16:30	2010-02-25 16:33
134	2010M	18.8	2010-01-13 03:21	9	2010-02-01 16:27	2010-02-16 16:08
135	2010N	16.7	2010-01-12 13:09	112	2010-01-27 21:44	2010-03-06 22:49
136	2010O	15.6	2010-01-24 11:28	60	2010-02-03 14:38	2010-04-02 19:36
137	2010P	18.3	2010-01-18 11:28	21	2010-02-06 15:47	2010-03-10 00:35
138	2010Q	19.2	2010-01-15 10:26	7	2010-02-09 21:33	2010-03-06 16:39
139	2010R	18.3	2010-01-15 12:17	39	2010-02-09 21:28	2010-03-06 20:52
140	2010S	18.4	2010-01-16 01:39	9	2010-02-01 16:41	2010-02-06 16:16
141	2010T	18.2	2010-01-25 13:14	4	2010-02-24 00:02	2010-03-07 23:42
142	2010U	16.0	2010-02-05 12:15	112	2010-01-23 18:24	2010-04-11 16:01
143	2010V*	14.3	2010-02-04 14:28	232	2010-01-27 20:47	2010-04-01 17:54
144	2010X	16.7	2010-02-07 04:48	5	2010-02-10 03:08	2010-02-11 02:23
145	2010Y	15.9	2010-02-08 10:51	146	2010-02-10 17:53	2010-04-12 18:52
146	2010Z	16.7	2010-02-03 09:16	111	2010-02-02 21:02	2010-03-23 17:29
147	2010ad	16.0	2010-02-18 16:02	54	2010-02-20 02:02	2010-05-08 17:55
148	2010af	17.2	2010-03-04 11:39	3	2010-04-13 12:09	2010-04-16 17:47
149	2010ag*	16.5	2010-03-05 17:03	132	2010-02-28 02:52	2010-04-24 23:16
150	2010ah	18.8	2010-02-23 11:44	1	2010-04-28 19:31	2010-04-28 19:31
151	2010ai*	16.9	2010-03-08 12:59	115	2010-03-06 21:11	2010-04-25 00:19
152	2010aj	17.1	2010-03-12 12:40	26	2010-03-17 21:08	2010-03-23 22:05
153	2010ak*	18.2	2010-03-11 16:10	17	2010-02-28 02:30	2010-04-01 01:33
154	2010al	17.8	2010-03-13 08:14	17	2010-03-05 18:46	2010-03-22 17:59
155	2010an	17.0	2010-03-11 16:17	145	2010-03-07 00:43	2010-05-31 22:06
156	2010ao	19.0	2010-03-18 13:43	30	2010-03-20 19:51	2010-04-24 23:28
157	2010ar	19.2	2010-02-15 10:03	7	2010-03-20 19:39	2010-03-23 17:12
158	2010at*	17.2	2010-03-19 12:05	7	2010-03-08 15:30	2010-04-30 00:16
159	2010au	16.7	2010-03-15 09:12	69	2010-03-01 11:45	2010-05-04 13:36
160	2010av	17.9	2010-03-19 15:07	2	2010-04-20 00:20	2010-04-20 01:06
161	2010aw	18.3	2010-03-19 17:16	2	2010-03-25 01:48	2010-03-28 01:28
162	2010ax	17.0	2010-03-15 14:41	92	2010-03-18 18:32	2010-05-02 13:57
163	2010ay*	17.5	2010-03-17 12:35	16	2010-03-09 17:42	2010-04-10 14:48
164	2010ba*	15.2	2010-03-21 11:58	87	2010-03-12 17:05	2010-05-08 13:02
165	2010bi	17.7	2010-03-24 11:04	6	2010-03-19 15:13	2010-04-12 13:46
166	2010bj	16.1	2010-03-27 07:17	20	2010-03-13 10:28	2010-04-12 13:48
167	2010bk	17.6	2010-04-04 12:27	1	2010-05-14 19:55	2010-05-14 19:55
168	2010bn	17.2	2010-04-05 11:44	18	2010-04-15 20:08	2010-05-16 19:33

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170	2010bs	17.5	2010-04-15 12:21	29	2010-04-13 14:21	2010-05-08 12:56
171	2010bu	16.9	2010-04-09 15:43	34	2010-04-16 22:29	2010-05-29 19:05
172	2010bx	19.0	2010-03-17 09:27	4	2010-04-29 17:21	2010-05-15 20:29
173	2010by	18.4	2010-03-18 15:14	6	2010-03-31 23:19	2010-04-29 22:35
174	2010bz	18.5	2010-03-19 13:18	6	2010-04-17 20:04	2010-04-29 21:46
175	2010cb	18.4	2010-03-21 12:24	8	2010-03-26 20:56	2010-04-29 18:33
176	2010cc	19.3	2010-03-21 12:14	1	2010-04-29 17:50	2010-04-29 17:50
177	2010cd	18.6	2010-04-05 11:58	4	2010-05-12 18:41	2010-05-14 17:41
178	2010ce	17.7	2010-04-08 09:35	7	2010-04-28 17:35	2010-05-15 18:40
179	2010cf	18.2	2010-04-09 15:23	20	2010-04-24 22:05	2010-05-29 19:30
180	2010cg	17.5	2010-04-09 15:30	27	2010-04-24 22:50	2010-05-29 20:19
181	2010ch	18.2	2010-04-09 15:05	15	2010-04-24 22:40	2010-05-19 23:15
182	2010ci	17.7	2010-04-12 07:53	4	2010-04-29 17:13	2010-04-29 18:00
183	2010cj	17.9	2010-04-12 08:48	23	2010-04-28 17:23	2010-05-27 17:57
184	2010ck	16.1	2010-04-25 14:04	37	2010-04-25 17:49	2010-07-22 18:53
185	2010cr*	17.0	2010-05-15 13:29	44	2010-05-02 14:31	2010-07-03 19:19
186	2010ct	19.2	2010-03-15 10:44	2	2010-03-19 18:23	2010-03-19 19:10
187	2010cu	17.7	2010-02-24 13:20	13	2010-03-01 00:06	2010-04-06 16:12
188	2010cv	18.8	2010-04-09 09:36	1	2010-05-29 18:40	2010-05-29 18:40
189	2010cw	17.8	2010-04-11 09:33	5	2010-04-07 12:30	2010-05-28 20:03
190	2010cx	18.3	2010-05-05 13:00	2	2010-06-03 21:40	2010-06-03 22:28
191	2010cy	17.0	2010-05-13 14:43	38	2010-05-19 23:09	2010-07-02 18:51
192	2010dd	17.2	2010-05-23 16:52	72	2010-05-26 19:46	2010-08-21 14:29
193	2010de	17.4	2010-04-10 16:12	5	2010-04-08 01:45	2010-05-29 19:13
194	2010df	18.9	2010-05-05 12:58	6	2010-05-29 17:56	2010-05-31 19:06
195	2010dg	19.2	2010-05-07 10:34	5	2010-05-28 18:28	2010-05-31 19:14
196	2010dh	18.0	2010-05-09 10:56	10	2010-05-28 17:51	2010-05-31 18:55
197	2010di	18.7	2010-05-12 08:52	2	2010-05-28 18:23	2010-05-28 18:47
198	2010dj	18.5	2010-05-12 11:57	15	2010-05-28 18:36	2010-06-27 18:48
199	2010dk	19.3	2010-05-16 14:28	20	2010-05-29 18:15	2010-07-02 18:48
200	2010dl	16.4	2010-05-24 21:35	12	2010-05-30 00:02	2010-07-13 23:02
201	2010dm	18.2	2010-05-23 12:11	30	2010-05-29 17:48	2010-06-27 19:30
202	2010dn*	17.2	2010-06-02 13:57	4	2010-06-01 21:39	2010-06-04 15:43
203	2010do	17.2	2010-06-02 13:57	8	2010-06-03 20:12	2010-06-06 19:20
204	2010dq	17.3	2010-06-03 00:15	37	2010-06-27 23:17	2010-07-22 22:44
205	2010dr	18.5	2010-06-03 23:52	4	2010-06-08 23:01	2010-08-28 22:40
206	2010dt	18.6	2010-06-01 16:43	44	2010-05-30 22:18	2010-07-19 20:36
207	2010du	18.8	2010-05-25 18:14	30	2010-06-08 18:59	2010-06-13 22:52
208	2010dw	17.3	2010-06-05 15:22	18	2010-06-08 20:02	2010-07-11 18:46
209	2010dy	17.9	2010-06-06 16:10	91	2010-06-12 19:56	2010-07-12 19:34
210	2010dz	18.1	2010-05-31 13:50	95	2010-06-12 18:31	2010-07-11 19:23
211	2010ea	17.6	2010-05-29 12:45	34	2010-05-29 22:28	2010-07-11 20:27

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212	2010eb	14.7	2010-06-12 01:21	35	2010-07-16 00:12	2010-08-25 16:34
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214	2010ef	19.1	2010-06-05 16:28	21	2010-06-09 22:18	2010-07-19 20:40
215	2010eg	18.5	2010-06-07 22:15	12	2010-07-13 23:55	2010-07-23 00:24
216	2010eh	17.4	2010-06-13 20:48	15	2010-08-04 21:10	2010-08-10 19:32
217	2010ei	17.5	2010-06-12 14:54	4	2010-05-31 19:31	2010-06-19 22:41
218	2010ej	19.2	2010-06-15 14:13	2	2010-07-01 19:59	2010-07-01 20:42
219	2010ek	18.8	2010-06-15 22:48	5	2010-06-19 21:58	2010-08-19 17:38
220	2010em	18.4	2010-06-18 22:54	10	2010-06-27 23:13	2010-08-14 20:26
221	2010en	19.0	2010-05-13 15:50	5	2010-06-28 18:54	2010-06-28 19:27
222	2010eo	17.6	2010-05-21 13:50	10	2010-06-28 19:37	2010-07-03 19:12
223	2010ep	18.1	2010-05-25 16:01	20	2010-06-28 19:34	2010-07-12 19:45
224	2010eq	17.6	2010-05-31 15:34	13	2010-06-28 18:58	2010-07-12 19:38
225	2010er	17.8	2010-06-09 15:50	61	2010-06-14 20:41	2010-08-07 22:00
226	2010es	18.8	2010-06-16 16:33	33	2010-07-02 21:31	2010-08-02 20:19
227	2010et	18.8	2010-06-16 17:16	57	2010-06-30 18:33	2010-08-28 18:25
228	2010eu	18.7	2010-06-20 21:31	10	2010-07-11 21:56	2010-08-02 21:54
229	2010ew	16.6	2010-06-28 18:37	63	2010-07-02 18:31	2010-08-13 17:41
230	2010ex	16.1	2010-07-01 23:00	70	2010-07-06 21:26	2010-09-20 18:38
231	2010fw	18.4	2010-07-02 17:47	3	2010-07-06 21:31	2010-08-21 14:47
232	2010fx	17.4	2010-07-04 23:03	1	2010-07-26 00:04	2010-07-26 00:04
233	2010ga	17.3	2010-07-08 00:34	23	2010-07-13 22:58	2010-08-19 16:57
234	2010gb	16.5	2010-07-11 15:38	68	2010-07-12 18:54	2010-08-30 17:40
235	2010ge	17.7	2010-06-10 15:43	3	2010-07-16 17:49	2010-07-16 19:12
236	2010gf	18.9	2010-07-11 01:01	15	2010-07-15 23:31	2010-10-01 21:07
237	2010gi	15.3	2010-07-18 17:21	144	2010-07-21 00:23	2010-09-07 11:51
238	2010gl	18.8	2010-07-18 16:31	41	2010-07-22 23:08	2010-09-06 13:47
239	2010gm	17.9	2010-07-19 17:33	121	2010-07-22 23:12	2010-09-07 14:10
240	2010gn	16.6	2010-07-07 17:17	162	2010-07-19 13:21	2010-09-24 14:42
241	2010gp	17.5	2010-07-14 16:53	42	2010-08-01 20:13	2010-08-31 17:25
242	2010gq	16.8	2010-07-21 00:17	5	2010-07-16 00:27	2010-09-07 17:30
243	2010gr	17.8	2010-07-29 02:34	2	2010-09-15 18:33	2010-09-15 18:33
244	2010gs	16.6	2010-08-01 20:45	15	2010-08-04 21:10	2010-08-10 19:32
245	2010gv	16.4	2010-08-09 17:58	181	2010-08-13 17:46	2010-09-28 16:32
246	2010ha	18.9	2010-08-19 02:00	32	2010-09-06 23:25	2010-11-15 18:58
247	2010hb	17.5	2010-08-24 03:07	114	2010-08-25 16:27	2010-10-14 00:45
248	2010hf	18.3	2010-08-31 06:37	7	2010-09-19 21:42	2010-11-12 16:40
249	2010hh	18.3	2010-09-01 17:59	94	2010-08-21 14:22	2010-10-19 15:33
250	2010hi	18.0	2010-09-01 18:13	102	2010-09-05 12:51	2010-11-18 18:10
251	2010hk	17.6	2010-09-02 03:37	68	2010-09-06 23:12	2010-10-21 02:23
252	2010hl	17.5	2010-09-02 17:16	113	2010-09-05 12:48	2010-10-22 16:49
253	2010hm	18.9	2010-09-02 23:35	17	2010-09-05 14:31	2010-09-19 22:45
254	2010ho*	16.6	2010-09-04 23:19	112	2010-08-31 22:13	2010-11-23 19:12

(Contd.)

No.	Name	Magnitude	Date and time	Number of frames	Date and time of first frame	Date and time of last frame
255	2010hp	17.1	2010-07-21 00:18	2	2010-08-29 23:42	2010-08-30 00:27
256	2010hq	15.2	2010-09-08 07:08	3	2010-09-29 00:21	2010-11-20 22:59
257	2010hr	16.8	2010-09-08 06:08	88	2010-09-11 16:57	2010-10-24 00:07
258	2010hs	18.6	2010-09-12 02:25	57	2010-09-12 21:30	2010-11-15 18:55
259	2010hu*	18.7	2010-09-11 23:22	9	2010-08-29 20:18	2010-10-05 19:29
260	2010hz	19.1	2010-09-12 01:53	66	2010-09-20 18:22	2010-11-01 16:46
261	2010ia	17.3	2010-09-16 03:56	66	2010-09-18 23:00	2010-11-05 19:52
262	2010ib	19.2	2010-09-05 01:25	5	2010-10-02 17:52	2010-10-14 00:00
263	2010ic	18.0	2010-09-20 22:19	26	2010-09-24 16:14	2010-11-03 17:14
264	2010id	18.9	2010-09-16 23:05	5	2010-09-28 13:55	2010-09-30 15:14
265	2010ie*	17.6	2010-09-23 07:08	17	2010-09-20 23:58	2010-11-12 22:20
266	2010if	19.3	2010-09-26 22:45	17	2010-09-28 16:44	2010-10-13 15:50
267	2010ig	18.9	2010-09-28 01:50	27	2010-09-30 14:22	2010-12-09 17:03
268	2010ii	18.0	2010-09-30 22:38	109	2010-10-03 15:32	2010-11-18 15:26
269	2010ij	15.9	2010-09-15 22:20	87	2010-10-04 14:12	2010-11-04 15:43
270	2010ik	18.7	2010-09-17 00:12	62	2010-10-05 18:21	2010-11-06 15:51
271	2010il	16.4	2010-09-29 20:29	2	2010-11-23 15:12	2010-11-23 16:00
272	2010io	17.5	2010-09-30 08:43	11	2010-10-26 23:28	2010-11-12 22:23
273	2010ip	18.1	2010-10-03 03:29	54	2010-10-12 19:21	2010-11-17 19:21
274	2010iq	18.5	2010-10-11 21:54	36	2010-10-13 23:15	2010-11-26 18:35
275	2010is	18.3	2010-10-12 23:19	35	2010-09-30 14:48	2010-11-25 15:50
276	2010it	17.0	2010-10-11 03:42	42	2010-10-15 21:45	2010-11-28 21:04
277	2010iw	16.4	2010-10-14 08:45	83	2010-10-21 00:56	2010-12-03 21:27
278	2010ix	18.0	2010-10-16 01:00	121	2010-10-25 20:43	2010-12-05 15:19
279	2010iz	17.2	2010-10-16 06:49	76	2010-10-09 23:58	2010-12-04 20:35
280	2010ja	17.9	2010-10-15 08:02	49	2010-10-26 00:54	2010-12-05 00:33
281	2010jc	18.2	2010-10-29 02:40	1	2010-11-03 19:57	2010-11-03 19:57
282	2010je	17.1	2010-11-02 17:18	22	2010-11-04 15:38	2010-12-19 23:26
283	2010jf	17.7	2010-10-20 03:40	2	2011-01-05 12:20	2011-01-05 13:09
284	2010jg	17.9	2010-10-11 22:04	28	2010-11-04 15:47	2010-11-29 15:33
285	2010ji	17.6	2010-10-17 01:45	46	2010-11-04 16:21	2010-12-05 11:11
286	2010jj	17.0	2010-11-03 02:06	27	2010-11-01 23:20	2010-11-23 21:13
287	2010jl	13.5	2010-11-03 09:42	33	2010-11-07 02:15	2011-01-30 16:24
288	2010jm	17.4	2010-11-02 03:46	76	2010-11-06 18:22	2010-12-22 16:48
289	2010jn	19.2	2010-10-12 09:37	15	2010-11-11 23:13	2010-11-18 00:03
290	2010jo	17.5	2010-11-06 00:57	51	2010-11-04 18:00	2011-01-01 15:22
291	2010js	18.1	2010-11-07 08:16	3	2010-11-15 19:31	2010-11-15 20:16
292	2010ju	16.8	2010-11-14 05:41	72	2010-11-17 19:13	2011-01-01 18:10
293	2010jv	16.3	2010-11-14 07:27	96	2010-11-11 21:26	2011-02-02 15:05
294	2010jw*	17.5	2010-11-14 08:47	62	2010-11-01 23:16	2011-02-03 14:30
295	2010jx	19.2	2010-10-28 01:19	29	2010-10-31 19:48	2010-12-12 18:48
296	2010jy	16.5	2010-10-30 23:09	31	2010-11-21 14:00	2011-01-21 11:43
297	2010jz	18.0	2010-11-02 07:17	57	2010-11-17 19:52	2010-12-18 23:55

(Contd.)

No.	Name	Magnitude	Date and time	Number of frames	Date and time of first frame	Date and time of last frame
298	2010ka	19.4	2010-11-07 03:26	11	2010-10-31 23:44	2010-12-10 17:46
299	2010kb	18.1	2010-11-10 08:20	5	2010-11-20 21:09	2011-01-31 16:47
300	2010kc	17.1	2010-11-15 23:20	23	2010-11-23 14:41	2011-01-03 16:38
301	2010kd	17.5	2010-11-14 12:08	10	2010-11-29 01:36	2011-02-11 16:02
302	2010ke*	18.1	2010-11-14 00:57	39	2010-11-08 19:54	2011-01-01 15:22
303	2010kf	17.5	2010-11-28 03:36	106	2010-12-01 17:38	2011-01-11 15:51
304	2010kg	18.8	2010-11-29 04:40	28	2010-12-04 17:49	2011-01-11 16:03
305	2010kh	17.4	2010-11-18 20:59	1	2010-12-05 10:52	2010-12-05 10:52
306	2010ki	16.9	2010-12-02 23:16	22	2010-12-04 10:45	2011-01-14 14:52
307	2010kj*	18.5	2010-11-02 02:48	27	2010-10-31 22:22	2010-12-22 15:33
308	2010kk	20.2	2010-11-08 03:53	2	2011-01-11 15:29	2011-01-11 16:15
309	2010kl	18.9	2010-11-16 11:27	17	2010-12-04 03:02	2011-02-06 18:59
310	2010km	18.8	2010-12-04 02:55	58	2010-12-08 20:12	2011-01-23 17:58
311	2010kn	18.5	2010-12-02 11:50	34	2010-11-18 23:52	2011-01-21 23:54
312	2010kp	17.9	2010-12-08 04:03	83	2010-12-10 15:21	2011-01-27 11:49
313	2010kq	18.3	2010-12-07 02:18	89	2010-12-10 10:54	2011-01-27 10:52
314	2010kr	18.1	2010-12-01 10:47	48	2010-12-10 22:01	2011-01-19 23:23
315	2010ks	17.0	2010-12-11 10:23	110	2010-12-18 20:27	2011-03-05 16:32
316	2010ku	16.8	2010-12-16 11:39	35	2010-12-29 23:51	2011-02-26 21:12
317	2010kv	18.5	2010-12-16 08:05	29	2010-12-27 20:44	2011-01-26 19:14
318	2010ky	19.5	2010-10-12 00:40	2	2010-11-01 19:10	2010-11-01 19:10
319	2010lc	18.6	2010-10-31 01:55	4	2010-12-04 16:16	2010-12-07 16:59
320	2010ld	18.6	2010-11-03 09:04	2	2010-12-10 00:24	2010-12-10 01:13
321	2010le*	18.2	2010-11-05 00:20	9	2010-11-03 14:33	2010-12-25 15:27
322	2010lf	17.3	2010-11-12 01:07	2	2010-11-21 17:59	2010-11-21 18:06
323	2010lg	18.1	2010-11-15 22:56	1	2010-12-26 12:49	2010-12-26 12:49
324	2010lh	19.3	2010-11-27 01:30	4	2010-12-04 15:06	2010-12-07 15:45
325	2010li	19.3	2010-11-28 02:07	6	2010-12-25 14:50	2011-01-10 15:36
326	2010lj	19.0	2010-12-03 08:54	49	2010-12-27 20:52	2011-02-03 17:06
327	2010lk	17.4	2010-12-03 09:15	27	2010-12-27 21:31	2011-02-25 17:38
328	2010ll	18.1	2010-12-10 04:50	8	2010-12-24 20:13	2011-01-24 18:00
329	2010ln	17.1	2010-12-25 03:20	191	2010-12-28 15:23	2011-02-08 13:27
330	2010lo	17.3	2010-12-15 12:31	95	2011-01-05 18:48	2011-02-03 21:40
331	2010lp	16.7	2010-12-29 02:54	116	2011-01-04 11:10	2011-02-13 11:39
332	2010lt	17.0	2010-12-31 06:06	2	2011-01-24 14:37	2011-01-24 15:24
333	2010lu	16.8	2010-12-08 09:06	111	2011-01-05 14:38	2011-01-27 14:49
334	2010ma	16.9	2010-12-19 00:48	23	2010-12-19 16:49	2010-12-21 16:08
335	2011B	15.8	2011-01-07 08:55	236	2011-01-13 10:31	2011-02-27 11:48
336	2011C	15.8	2011-01-05 11:17	59	2011-01-13 20:32	2011-02-22 18:24
337	2011D	18.2	2011-01-05 03:02	1	2011-01-21 14:57	2011-01-21 14:57
338	2011F	18.7	2011-01-07 12:38	1	2011-01-28 20:27	2011-01-28 20:27
339	2011G	19.3	2011-01-08 12:09	11	2011-01-13 21:11	2011-02-25 13:13
340	2011H	15.6	2011-01-04 02:23	168	2011-01-16 15:46	2011-02-23 12:48
341	2011J	18.8	2011-01-08 10:50	22	2011-01-24 15:51	2011-03-26 15:46
342	2011K	15.1	2011-01-13 04:45	24	2011-01-19 16:31	2011-02-04 15:30

(Contd.)

No.	Name	Magnitude	Date and time	Number of frames	Date and time of first frame	Date and time of last frame
343	2011L	17.0	2011-01-14 23:40	35	2011-01-27 11:37	2011-02-13 11:21
344	2011M	18.2	2011-01-19 05:00	95	2011-01-27 10:59	2011-03-10 11:53
345	2011O	18.1	2011-01-18 13:54	3	2011-01-12 23:20	2011-04-08 16:49
346	2011P*	18.6	2011-01-05 02:25	3	2011-01-01 15:49	2011-01-26 13:39
347	2011Q	19.0	2011-01-05 09:19	7	2011-02-08 13:30	2011-03-25 12:24
348	2011T	16.3	2011-01-28 17:10	182	2011-02-06 19:12	2011-03-20 00:36
349	2011U	17.6	2011-01-28 04:13	92	2011-02-04 11:56	2011-03-19 16:26
350	2011V	16.0	2011-01-28 09:27	5	2011-01-29 22:23	2011-03-11 15:54
351	2011aa	16.1	2011-02-06 07:36	81	2011-01-23 18:17	2011-04-23 19:45
352	2011ac	17.7	2011-02-11 08:43	10	2011-02-28 12:46	2011-03-26 22:52
353	2011ad*	19.0	2011-02-11 11:46	4	2011-01-29 21:56	2011-04-23 16:13
354	2011af	16.7	2011-01-11 02:25	7	2011-01-19 11:27	2011-01-26 14:08
355	2011ai	17.0	2011-02-24 14:29	4	2011-03-12 16:20	2011-05-07 15:19
356	2011aj	17.3	2011-02-18 16:50	4	2011-03-12 21:32	2011-05-05 19:22
357	2011ak	17.2	2011-02-09 12:00	14	2011-01-30 00:35	2011-04-27 14:49
358	2011al	18.7	2011-02-05 10:26	6	2011-01-27 18:03	2011-04-01 13:34
359	2011ao	17.1	2011-03-03 11:53	7	2011-03-14 15:17	2011-05-23 16:40
360	2011aq	18.0	2011-01-24 02:42	1	2011-02-26 13:10	2011-02-26 13:10
361	2011au	19.0	2011-03-05 09:33	1	2011-03-30 20:24	2011-03-30 20:24
362	2011av	17.6	2011-03-08 13:36	6	2011-03-14 16:21	2011-04-25 17:21
363	2011ax	18.3	2011-03-10 07:36	2	2011-03-04 11:35	2011-04-19 16:10
364	2011ay	17.7	2011-03-18 07:02	4	2011-03-04 10:35	2011-03-08 12:24
365	2011az*	16.2	2011-03-18 12:53	9	2011-03-14 15:34	2011-05-07 13:36
366	2011bc	17.3	2011-04-01 12:04	9	2011-03-27 15:36	2011-05-19 14:09
367	2011bd	16.0	2011-03-24 17:47	7	2011-05-11 14:16	2011-05-15 18:23
368	2011be	17.7	2011-03-25 09:22	3	2011-04-20 14:06	2011-05-13 15:06
369	2011bg	16.7	2011-03-26 11:56	12	2011-03-14 15:06	2011-05-14 15:08
370	2011bh	17.5	2011-03-29 07:45	1	2011-03-25 14:13	2011-03-25 14:13
371	2011bi	17.1	2011-04-04 17:10	2	2011-03-31 20:16	2011-03-31 20:24
372	2011bk*	15.8	2011-03-07 16:20	8	2011-03-01 21:06	2011-04-27 16:59
373	2011bl	16.9	2011-04-05 13:34	6	2011-04-05 17:40	2011-05-18 17:08
374	2011bm	17.0	2011-04-04 12:56	5	2011-04-14 15:33	2011-05-03 13:51
375	2011bn	18.9	2011-03-08 16:16	2	2011-05-23 16:05	2011-05-23 16:52
376	2011bp	18.2	2011-04-06 11:12	2	2011-04-21 17:24	2011-04-21 18:18
377	2011bq	17.9	2011-04-15 18:29	2	2011-04-09 20:15	2011-04-09 21:05
378	2011br	18.2	2011-04-09 15:06	4	2011-03-27 12:44	2011-04-17 19:00
379	2011bs	18.5	2011-03-27 14:36	2	2011-03-21 19:42	2011-05-11 16:45
380	2011bt*	19.2	2011-03-28 12:52	8	2011-03-23 16:06	2011-05-01 17:23
381	2011by	14.2	2011-04-26 11:55	25	2011-04-13 13:42	2011-05-24 13:34
382	2011bz	17.4	2011-04-24 14:04	12	2011-05-22 19:52	2011-05-22 22:30
383	2011ca	17.2	2011-04-26 12:31	1	2011-05-05 15:25	2011-05-05 15:25
384	2011cc	17.7	2011-03-17 16:33	2	2011-04-26 19:13	2011-04-26 20:00
385	2011cg	15.7	2011-04-14 14:59	44	2011-04-26 19:45	2011-05-25 00:02
386	2011ch	16.1	2011-04-27 13:02	27	2011-05-13 14:25	2011-05-25 00:05
387	2011ck*	15.9	2011-05-12 14:00	1	2011-05-05 17:12	2011-05-05 17:12

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